Helminth communities of fish as ecological indicators of lake health

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SUMMARY

This paper deals largely with the dynamics and changes in the helminth parasite communities of fish along the trophic gradient of lakes. The use of parasitological community data as a bioindicator of environmental health underlines the need to study parasite communities at comparable localities with known pollution levels. The comparison of the conditions in different habitats might be helpful to differentiate between normal fluctuations in ambient conditions and pollution-mediated effects. Therefore, the present study was designed to examine the community structure of parasites in snow trout (*Schizothorax niger* Heckel) inhabiting 3 lakes of contrasting trophic status in Kashmir. The idea of selecting the lakes, namely Anchar (strongly hypereutrophic), Dal (eutrophic) and Manasbal (mesotrophic) for this study was intentional as they depict different trophic gradients and exhibit the desirable pattern which was a prerequisite for this study. The findings presented in this article suggest an apparent lake-wise gradient in community structure, as the increase in trematode and cestode infections in Anchar was markedly greater, to levels clearly distinguishable from those in the other two water bodies. We conclude that human-induced eutrophication of lakes modifies the parasite community at component level and community-level studies on parasites may provide information on health status of lakes.

Key words: parasite communities, fishes, lakes, eutrophication, bioindicator, ecosystem health.

INTRODUCTION

Human activities have severely affected the condition of freshwater ecosystems worldwide. Cultural eutrophication of lakes by the addition of organic matter and nutrients, such as phosphate and nitrate, has resulted in changes in water quality and ensuing changes in the structure of aquatic communities. Although the importance of zooplanktonic, benthic and fish communities as biological indicators has been widely recognized in many Himalayan lakes of Kashmir, the collection of even basic parasitological community data on lakes is still in its infancy (Shah and Yousuf, 2007; Shah, 2010). Given that in an aquatic ecosystem the parasite communities of fish may provide information on ecosystem conditions due to their intimate contact with both the host and the aquatic environment, numerous authors concluded that parasite assemblages should be considered not only for their influence on fish health but also for their own changes in prevalence, abundance and diversity in response to environmental quality (Koskivaara, 1992; Bagge and Valtonen, 1996; Marcogliese and Cone, 1991, 1996, 1997; Valtonen *et al.* 1997, 2003; Lafferty, 1997, 2008; Landsberg *et al.* 1998; Lafferty and Kuris, 1999). The present study, therefore, was carried out on 3 lakes of contrasting trophic status in Kashmir and is an attempt to evaluate how the structure of parasite communities of fish may vary as a function of lake productivity.

MATERIALS AND METHODS

In the present study, data were collected from 3 valley lakes of Kashmir, namely Anchar Lake (34°07′31″–34°10′11″N and 74°46′23″–74°48′00″E), Dal Lake (34°04′56″–34°08′57″N and 74°49′48″–74°52′51″E) and Manasbal Lake (34°14′38″–34°15′24″N and 74°39′06″–74°41′19″E). The selection of 3 lakes was based on their degree of trophic status (Zutshi *et al.* 1980; Pandit and Yousuf, 2002; Shah, 2010). Detailed limnological descriptions of the study lakes were presented by Shah (2010). For a number of decades both Anchar and Dal lakes have been subject to increasing cultural eutrophication, and are hypertrophic and eutrophic respectively, whereas the Manasbal Lake is a mesotrophic lake with minimal human influence. The Anchar is the shallowest of the three lakes, whereas the Manasbal is the deepest. The study of physico-chemical characteristics is a primary consideration for assessing the water quality of an

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aquatic system (Hutchinson, 1957). In order to have an idea about the status of their water quality, the study lakes were visited within a 3-day period in each month starting from June 2006 through May 2008 for the collection of water samples. In each lake, sampling was undertaken at 5 sampling points that characterized the different regions of the lakes with latitudinal and longitudinal data for each site being recorded with a hand-held global positioning system (GPS). The analytical determinations were done in accordance with the standard methods (APHA, 1998; Wetzel and Likens, 2000). Crustaceans, mollusks and oligochaetes, which are reported to be serving as intermediate hosts for many fish parasites, were sampled. The sampling of crustacean hosts was made with the help of a zooplankton net, while for collecting gastropod snails and oligochaetes, sediment samples were procured. Quantitative enumeration of various intermediate hosts was done in accordance with standard methods (APHA, 1998; Wetzel and Likens, 2000). Identification of different intermediate host groups was done with the help of keys from Stephenson (1923), Goodnight (1959), Tressler (1959), Yeatman (1959), and Pennak (1978).

The model fish host chosen for this study was the snow trout, *Schizothorax niger* Heckel. The fish was selected on the basis of its endemic nature and common accessibility in all the 3 localities (Yousuf *et al*. 2002). Moreover, the fish is the only species of the schizothoracine group that has adapted completely to lacustrine habitats and does not show the spawning migration towards the upper reaches of the streams, which is the characteristic feature of this group. Furthermore, the fish is facing considerable stress as the changing ecology of waters and eutrophication of lakes has resulted in a significant decline in the populations of this native fish over the years. A total of 450 specimens of fish were examined for parasites from June 2006 to May 2008 on a monthly basis. Since it was not possible to collect consistent or replicable fish samples from highly eutrophic Anchar Lake, therefore the sample size from each lake was adjusted to the maximum number of fish collected from Anchar Lake that was mostly 6–7 on each occasion to make the samples comparable. Even though the individual monthly samples were relatively small, this equal consistency ensured that observed changes in the parasite community were real and not artifacts of sampling or procedure. The fish samples of comparable size-class were obtained from the catches of local fishermen. Fish were examined for metazoan parasites according to standard necropsy techniques adopted from Weesner (1960) and Schmidt (1992). For identification of parasites, the works of Yamaguti (1958, 1959, 1963*a*,*b*), Fotedar (1958), Kaul (1986), Fayaz and Chishti (1994, 2000) and Ara *et al*. (2000) were consulted.

The level of parasite infection was assessed according to the terminology outlined by Bush *et al*. (1997). Helminth community structure was studied at component community level (Bush *et al*. 1997). The measures of component community structure studied include: the component community richness (CCR), Shannon-Wiener index of diversity, and Simpson's diversity index. To focus attention on the dominant helminth species in each component community in each locality, the Berger-Parker dominance index was also calculated which measures the proportion of total catch that is due to the dominant species (diversity is lower when there is stronger dominance in the sampling unit by one or few species). The calculation of all indices was performed following the protocols of Washington (1984) and Stilling (1996). The importance of each parasite guild (by pooling parasites in the following categories, i.e. autogenic parasites, and allogenic parasites) within each component community was evaluated by calculating the proportion of individual parasites that it contributed to the assemblage. A species was designated as component species if it was present in >10% of the host sample (Bush *et al*. 1990). Within a parasite community, the relative abundance of each parasite species, or species evenness, is a key component of the structure of that community (Poulin, 1996). Therefore, species abundance distributions were constructed by plotting the relative abundance of each species, expressed as a percentage of the total number of individual helminths in the community, against its rank, when all species are ranked from most to least abundant (Poulin *et al*. 2008). One-way analysis of variance (ANOVA) was employed to determine significant differences between the lakes and Tukey's HSD-test was used to make post-hoc pair-wise comparisons. All correlations were carried out using Pearsons's test. The significance of all statistical analyses was established at P values <0·05. All statistical tests were performed using SPSS software (Statistical Package for Social Science) version 12.0 for Windows.

RESULTS

In general, the data on limnological parameters revealed some notable differences among the lakes pointing to differences in their trophic status (Table 1). Secchi depth is a measure of water clarity and is used as a visual index of general lake productivity. It is a function of reflection of light from the surface of the disc and therefore is affected by the absorption characteristics of the water, and of dissolved and particulate matter contained in the water (Wetzel and Likens, 2000). The transparency in Anchar Lake was relatively on the lower side and was influenced by turbidity. On the basis of maximum transparency values, the differences among the lakes were significant ($F_{2,69} = 89 \cdot 544$, $P < 0 \cdot 001$ respectively); Tukey's HSD test revealed that all the lakes differed significantly from one another.

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Table 1. Limnological characteristics of the three study lakes

(Values are expressed as mean ± S.D.)

Parameter	Manasbal Lake	Dal Lake	Anchar Lake
Transparency (m)	3·3 ± 0·73	1·9 ± 0·41	1·1 ± 0·56*
Maximum depth (m)	11·7 ± 0·49	2·27 ± 0·32	1·41 ± 0·52*
Nitrate-Nitrogen (μg/L)	88 ± 79·30	228 ± 258·78	463 ± 512·52*
Total phosphorus (μg/L)	230 ± 103·33	282 ± 150·13	752 ± 559·02*
Total dissolved solids (mg/L)	191 ± 61·13	192 ± 69·20	287 ± 109·89*
Cyclopoid copepods (organisms/m^3)	25683 ± 41819·9	40342 ± 83815·7	54625 ± 52261·9
Lymnaeid snails (organisms/m^2)	130 ± 32·2	192 ± 46·0	405 ± 223·30*
Planorbid snails (organisms/m^2)	44 ± 9·1	87 ± 26·5	1257 ± 388·30*
Tubificid oligochaetes (organisms/m^2)	23 ± 12·25	83 ± 32	1242 ± 564·36*
Amphipods (organisms/m^2)	9 ± 30·89	7 ± 25·69	6 ± 20·50
Ostracods (organisms/$m^{3)}$	482 ± 702·18	538 ± 655·74	453 ± 567·70

* Values significant at $P < 0{\cdot}05$.

The depth of an aquatic body plays an important role in concentrating ions in water mass (Hutchinson, 1957). Moreover, shallow basins are considered to be the best-suited habitats for emergent vegetation and benthic invertebrates (Wetzel, 2001). Among the sampling sites within each lake, the depth showed a distinct gradation. The maximum depth recorded at the central site of the lakes varied from 2 m in Anchar to 3 m in Dal to 12·2 m in Manasbal. In respect of maximum depth, the lakes differed significantly from each other ($F_{2,69} = 3842{\cdot}871$, $P < 0{\cdot}001$).

Phosphates and nitrates are essential for the growth of primary producers and are usually present in low concentrations in natural unpolluted fresh waters (Wetzel, 2001). In the eutrophication of lakes, phosphorus has been implicated as the main causal factor (OECD, 1982). It is generally acknowledged that phosphorus is not only an essential nutrient but is also a limiting nutrient for aquatic plant growth and is in fact a key element in enhancing and accelerating eutrophic conditions. The increased level of phosphates in a water body is also an indication of sewage contamination (Hutchinson, 1957). The concentrations of phosphates and nitrates were in the order of Anchar > Dal > Manasbal. The differences between the lakes were again significant for both nitrate-N and TP ($F_{2,357} = 38{\cdot}654$, $P < 0{\cdot}001$; $F_{2,357} = 86{\cdot}325$, $P < 0{\cdot}001$ respectively). Furthermore, the values recorded in Anchar were significantly higher than those recorded in Dal and Manasbal (Tukey HSD-test, $P < 0{\cdot}001$) for total P, while the differences recorded in Dal and Manasbal were not statistically significant between the two lakes (Tukey HSD-test, $P = 0{\cdot}467$).

Patterns in total dissolved solids (TDS) closely followed those of inorganic nutrients; comparatively higher values were recorded in Anchar followed by Dal and Manasbal. The inter-lake differences were statistically significant ($F_{2,357} = 53{\cdot}621$, $P < 0{\cdot}001$); albeit, the values in Anchar were significantly higher than those obtained in Dal and Manasbal (Tukey HSD-test, $P < 0{\cdot}001$). In comparison, there were no significant differences in TDS values between Dal and Manasbal (Tukey HSD-test, $P = 0{\cdot}990$). The density of free-living intermediate hosts was considered as a factor that might mirror the water quality of study lakes; therefore, the strategy of sampling invertebrate hosts on the basis of abundance was used to estimate their density. The densities of different free-living intermediate host groups are shown in Table 1. In particular, the interlake comparison revealed a much higher numerical dominance and proportion of the planorbid snails and tubificid oligochaetes in Anchar compared to Dal and Manasbal. The numbers and proportions of these two benthic groups are often used as symbolic indicators of organic pollution, due to their dominant status in polluted waters (Marcogliese *et al*. 2001; Lin and Yo, 2008).

A total of 7 helminth parasite species were recorded during the investigation period. These included *Diplozoon kashmirensis* Kaw, *Clinostomum schizothoraxi* Kaw, and *Posthodiplostomum cuticola* Dubios (= *Neascus cuticola* Nordmann) from Trematoda, *Bothriocephalus acheilognathi* Yamaguti and *Adenoscolex oreini* Fotedar from Cestoda, and *Pomphorhynchus kashmirensis* Kaw and *Neoechinorhynchus manasbalensis* Kaw from Acanthocephala. However, nematode parasites were not reported from any lake during the whole study period. For all the parasites analysed in this study, there is an indication of change in prevalence along the seasonal gradient of water temperature. Therefore, interlake comparisons were based on all data combined over all months for a year as well as for the whole investigation period so as to present a general picture of community structure in each lake rather than comparing the data from the same or closest months in each year to minimize the variations due to seasonality. The inter-annual variations recorded for each lake indicating the prevalence, mean intensity and mean abundance are presented in Table 2. The data regarding component

Table 2. Overall and year-wise pattern in prevalence, mean intensity (±S.D.) and mean abundance (±S.D.) of parasites in *Schizothorax niger*

Parasite	Lake	Parameter	1st year	2nd year	Overall	Component species
Diplozoon kashmirensis	Manasbal	P (%)	9·3	13	11·1	Yes
		MI	1·3(±1·05)	1·6(±1·44)	1·5(±1·24)	
		MA	0·2(±0·19)	0·3(±0·27)	0·2(±0·23)	
	Dal	P (%)	20·4	20·6	20·5	Yes
		MI	2·3(±1·82)	1·9(±1·87)	2·1(±1·82)	
		MA	0·7(±0·67)	0·6(±0·75)	0·7(±0·70)	
	Anchar	P (%)	34	27·3	30·5	Yes
		MI	2·9(±2·45)	2·6(±1·89)	2·7(±2·03)	
		MA	1·5(±1·27)	1(±0·89)	1·2(±1·08)	
Clinostomum schizothoraxi	Manasbal	P (%)	7·4	12	9·7	No
		MI	1·3(±1·23)	1·5(±1·17)	1·4(±1·18)	
		MA	0·2(±0·19)	0·3(±0·21)	0·25(±0·20)	
	Dal	P (%)	17·2	16·9	17	Yes
		MI	2·2(±1·28)	1·7(±1·17)	1·9(±1·23)	
		MA	0·4(±0·28)	0·4(±0·27)	0·4(±0·27)	
	Anchar	P (%)	23·2	29·4	26·4	Yes
		MI	2·7(±2·06)	2·7(±1·56)	2·7(±1·70)	
		MA	0·9(±0·78)	0·9(±0·73)	0·9(±0·74)	
Posthodiplostomum cuticola	Manasbal	P (%)	8·5	10·4	9·4	No
		MI	3·6(±3·55)	2·3(±2·27)	3(±2·99)	
		MA	0·4(±0·41)	0·4(±0·41)	0·4(±0·40)	
	Dal	P (%)	14·8	16	15·4	Yes
		MI	5·2(±3·86)	5(±3·65)	5·1(±3·67)	
		MA	0·8(±0·75)	1(±0·74)	0·9(±0·74)	
	Anchar	P (%)	47·9	34	40·6	Yes
		MI	23(±37·77)	9·4(±5·15)	15·9(±26·90)	
		MA	12·7(±22·80)	3·6(±2·76)	7·9(±16·31)	
Adenoscolex oreini	Manasbal	P (%)	3·3	4	3·6	No
		MI	1·4(±2·27)	1·2(±2·17)	1·3(±2·18)	
		MA	0·1(±0·20)	0·2(±0·36)	0·2(±0·29)	
	Dal	P (%)	7·4	5·7	6·5	No
		MI	2·2(±2·52)	1·3(±2·10)	1·8(±2·31)	
		MA	0·3(±0·35)	0·2(±0·38)	0·3(±0·36)	
	Anchar	P (%)	19·5	19·9	19·7	Yes
		MI	3·2(±2·91)	3·2(±3·31)	3·2(±3·06)	
		MA	1·1(±1·11)	1·1(±1·23)	1·1(±1·15)	
Bothriocephalus acheilognathi	Manasbal	P (%)	9·6	13·6	11·2	Yes
		MI	4·9(±3·60)	3·6(±2·31)	4·3(±3·07)	
		MA	0·5(±0·39)	0·5(±0·44)	0·5(±0·41)	
	Dal	P (%)	18·5	19·4	19	Yes
		MI	6·1(±12·4)	3·7(±2·69)	4·9(±8·88)	
		MA	1·1(±1·12)	0·7(±0·53)	0·9(±0·87)	
	Anchar	P (%)	31·7	28·4	29·9	Yes
		MI	6·7(±4·07)	7·6(±5·53)	7·1(±4·75)	
		MA	2·1(±1·59)	2·1(±1·92)	2·1(±1·72)	
Pomphorhynchus kashmirensis	Manasbal	P (%)	9·1	5·6	7·4	No
		MI	1·9(±1·81)	0·8(±1·27)	1·4(±1·62)	
		MA	0·3(±0·30)	0·1(±0·22)	0·2(±0·27)	
	Dal	P (%)	4·5	4·7	4·6	No
		MI	1·2(±2·48)	0·8(±1·42)	1(±1·99)	
		MA	0·2(±0·45)	0·1(±0·26)	0·15(±0·36)	
	Anchar	P (%)	0·9	0	0·4	No
		MI	0·3(±0·87)	0(±0)	0·1(±0·61)	
		MA	0·03(±0·09)	0(±0)	0·01(±0·06)	
Neoechinorhynchus manasbalensis	Manasbal	P (%)	2·2	2·8	2·5	No
		MI	0·3(±0·69)	0·7(±1·61)	0·5(±1·23)	
		MA	0·04(±0·10)	0·11(±0·26)	0·1(±0·20)	
	Dal	P (%)	1	3·1	2·1	No
		MI	0·3(±0·87)	0·3(±0·62)	0·3(±0·74)	
		MA	0·03(±0·11)	0·04(±0·10)	0·04(±0·11)	
	Anchar	P (%)	0	1	0·5	No
		MI	0(±0)	0·1(±0·29)	0·1(±0·21)	
		MA	0(±0)	0·01(±0·03)	0(±0·02)	

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Table 3. Diversity characteristics of the helminth component communities of *Schizothorax niger* in the three lakes

Index	Lake	Trophic status	1st year	2nd year	Overall
Component community richness (CCR)	Manasbal	Mesoeutrophic	3·8(±2·42)	3·4(±2·35)	3·6(±2·34)
	Dal	Eutrophic	4(±1·76)	3·8(±2·18)	3·9(±1·94)
	Anchar	Hypereutrophic	4·1(±1·89)	4·2(±1·75)	4·1(±1·20)
Shannon's index (H')	Manasbal	Mesoeutrophic	1·1(±0·13)	1·06(±0·69)	1·08(±0·68)
	Dal	Eutrophic	1·13(±0·58)	0·97(±0·55)	1·05(±0·56)
	Anchar	Hypereutrophic	1·08(±0·53)	1·14(±0·53)	1·11(±0·39)
Simpson's index (D)	Manasbal	Mesoeutrophic	0·20(±0·13)	0·20(±0·14)	0·20(±0·13)
	Dal	Eutrophic	0·24(±0·14)	0·26(±0·15)	0·25(±0·14)
	Anchar	Hypereutrophic	0·43(±0·24)	0·31(±0·16)	0·37(±0·17)
Berger-Parker index (d)	Manasbal	Mesoeutrophic	0·26(±0·17)	0·26(±0·18)	0·26(±0·17)
	Dal	Eutrophic	0·32(±0·17)	0·33(±0·19)	0·33(±0·18)
	Anchar	Hypereutrophic	0·55(±0·27)	0·44(±0·22)	0·49(±0·19)
Dominant species	Manasbal	Mesoeutrophic	*Bothriocephalus acheilognathi*	*Bothriocephalus acheilognathi*	*Bothriocephalus acheilognathi*
	Dal	Eutrophic	*Bothriocephalus. acheilognathi*	*Posthodiplostomum cuticola*	*Posthodiplostomum cuticola*
	Anchar	Hypereutrophic	*Posthodiplostomum cuticola*	*Posthodiplostomum cuticola*	*Posthodiplostomum cuticola*

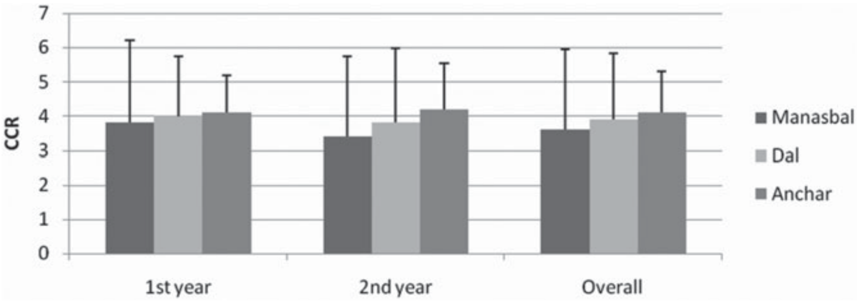

Fig. 1. Overall and year-wise pattern of component community richness (CCR) in *Schizothorax niger* (Bars represent standard deviation).

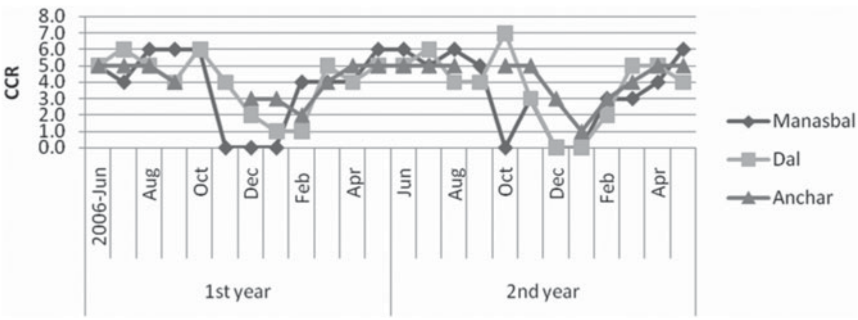

Fig. 2. Monthly values of component community richness (CCR) in *Schizothorax niger* in the three lakes.

community richness, Shannon's index, Simpson's index and Berger-Parker dominance index are given in Table 3. For Manasbal Lake, component communities were less species rich than those of Dal and Anchar, which harboured the richer communities (Fig. 1); however, the differences were not significant (one way ANOVA; $F_{2,66} = 0·482$, $P = 0·620$). When the total number of parasite species is considered, a clear seasonality, reflected by an increase from March to October with minimal or zero values in winter, was observed in all lakes (Fig. 2).

The component community in *S. niger* of Anchar and Dal was overwhelmingly dominated by larval digenean *P. cuticola*, as indicated by the relative proportion of this species in the component community, while *B. acheilognathi* contributed a major proportion to the component community in Manasbal. The intestinal community in Anchar and Dal was, however, dominated by *B. acheilognathi* and all other intestinal species occurred at low prevalence and formed a small proportion of total number of intestinal helminths. On a monthly basis there was

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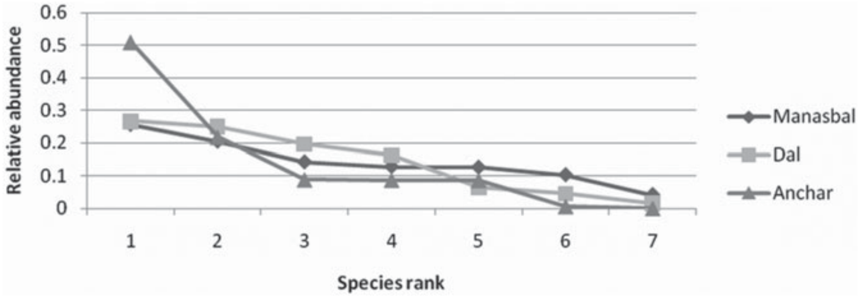

Fig. 3. Species abundance distributions in helminth communities of *Schizothorax niger* in the three lakes.

no consistent dominance by either autogenic or allogenic species in Manasbal and Dal, but in the case of Anchar Lake the relative proportions of *P. cuticola* were considerably and consistently higher. By way of comparison, the order of dominance in the 3 lakes was:

B. acheilognathi > *P. cuticola* > *P. kashmirensis* > *C. schizothoraxi* > *D. kashmirensis* > *A. oreini* > *N. manasbalensis* in Manasbal; *P. cuticola* > *B. acheilognathi* > *C. schizothoraxi* > *D. kashmirensis* > *A. oreini* > *P. kashmirensis* > *N. manasbalensis* in Dal; and *P. cuticola* > *B. acheilognathi* > *D. kashmirensis* > *C. schizothoraxi* > *A. oreini* > *P. kashmirensis* > *N. manasbalensis* in Anchar.

The differences among localities were reflected strongly in the changes in relative abundance of the species. In Anchar, some of the species were accidentals like *P. kashmirensis* and *N. manasbalensis* and occurred at low frequency, and thereby gave an erratic element to the community, while a few like *P. cuticola* and *C. schizothoraxi*, which occurred at higher frequency, gave a regular degree of continuity to community composition. This was depicted by the abundance-versus-rank plots that displayed different shapes in the 3 lakes (Fig. 3). These plots rank the species from most to least numerically abundant on the x-axis. In Anchar Lake, a steep drop in abundance was noted from first- to second- and third-ranked species, then levelling off for species of intermediate ranks. The most abundant species, i.e. *P. cuticola*, accounted for about one half of all individuals in the parasite community in Anchar. However, in Dal there was a gradual drop in ranks from first- to last-ranked species. The plot was gentler in Manasbal and the ratio in abundance between the first-, second and third-most abundant species was comparatively lower and then a levelling off was observed. Thus, the differences in abundance between the 2 most abundant species were not wide in Dal and Manasbal. The proportion of helminths in component communities varied from locality to locality in respect of the supply of parasite species available. In general, the parasite community in Anchar was dominated by allogenic individuals, whereas in Dal and Manasbal it was dominated by autogenic individuals. Additionally,

Table 4. Proportion (in percent) of allogenic and autogenic components in parasite communities of *Schizothorax niger* in the three lakes

Component	Manasbal Lake	Dal Lake	Anchar Lake
Autogenic Parasites (direct L/C)	13	16	9
Autogenic Parasites (indirect L/C)	54	38	31
Allogenic Parasites (indirect L/C)	33	46	60

the infestation pattern of allogenic parasites was highly overdispersed in Anchar. In contrast, the number of individual parasites recovered per host was comparatively reduced in Manasbal and Dal. On the monthly basis also the majority of communities were dominated by autogenic species in both Dal and Manasbal, whereas there was a consistent dominance of allogenic species in Anchar. However, differences in dominance pattern between the years reflect changes in relative abundance of parasites in each community. In Anchar, the allogenic species form a greater proportion of individuals in the communities although there are collectively more autogenic species, but in Dal and Manasbal, a reverse trend was observed (Table 4). The proportion of allogenic versus autogenic components varied among the lakes and was significantly affected by the character of habitat which affected the abundance patterns of the respective parasites.

The overall Shannon's diversity index was comparatively higher in Anchar followed by Manasbal and Dal. Although the parasite communities in hosts from Manasbal had a higher mean index than did the communities from Dal, the differences were not significantly different among the lakes (one-way ANOVA; $F_{2,66} = 0{\cdot}066$, $P = 0{\cdot}936$). During the 1st year, the diversity was highest in Dal followed by Manasbal and Anchar, while the order was Anchar followed by Manasbal and Dal during the 2nd year. Pearson correlation coefficient indicated a significant positive correlation between Shannon's index (H') and component community richness (CCR) across all localities ($r_p = 0{\cdot}987$, $P < 0{\cdot}001$ in Manasbal;

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$r_p = 0{\cdot}875$, $P < 0{\cdot}001$ in Dal; $r_p = 0{\cdot}776$, $P < 0{\cdot}001$ in Anchar).

The Simpson's index and Berger-Parker index depicted a parallel trend with the highest values reported from Anchar followed by Dal and Manasbal. The differences among the lakes were significant statistically (one-way ANOVA; $F_{2,66} = 7{\cdot}407$, $P = 0{\cdot}001$ and $F_{2,66} = 9{\cdot}843$, $P < 0{\cdot}001$ respectively). The Anchar differed significantly from both Dal and Manasbal (Tukey HSD-test), while the values did not vary significantly between Manasbal and Dal (Tukey HSD-test, $P = 0{\cdot}480$ and $P = 0{\cdot}400$ respectively for Simpson's index and BP index). The comparatively high values for Berger-Parker dominance index in Anchar suggested the presence of some heavily infected hosts in the sample, as was also indicated by the maximum intensity values. The prevalence of dominance was high in Anchar Lake with the Berger-Parker index exceeding 0·50 in 43% of the communities compared to 17% in Dal Lake, the corresponding values never exceeded 0·50 in Manasbal Lake. However, the overall species richness and Shannon's index were comparatively higher in Anchar Lake than both Dal and Manasbal, reflecting a decrease in the proportion of zero infections in the former lake or total absence of infections in the last 2 lakes, i.e. exhibiting zero diversity, during winter months. In Anchar Lake, the overall picture is of a component community exhibiting heavy dominance by one species but surprisingly the diversity is higher than the other 2 lakes, and also the diversity varies within very narrow limits. Moreover, Simpson's index (D) correlated positively and significantly with Berger-Parker (d) index in all the 3 lakes ($r_p = 0{\cdot}947$, $P < 0{\cdot}001$ in Manasbal; $r_p = 0{\cdot}968$, $P < 0{\cdot}001$ in Dal; $r_p = 0{\cdot}962$, $P = 0{\cdot}005$ in Anchar).

In general, the total number of parasite species recovered from *S. niger* was 7; but, apart from 1 case (October of 2nd year in Dal Lake) the monthly analysed component communities never attained the total species numbers recorded for the whole study period. This seems to be related to respective seasonality of parasites and as well as to the rare status of some species. In fact, much of the increased richness in Anchar Lake was due to species which occurred at low levels of abundance and formed only a small portion of the total abundance. This is further supported by data on Berger-Parker dominance index, and Simpson's index values that were found to be comparatively higher in Anchar Lake than in Dal and Manasbal.

DISCUSSION

The study revealed the helminth component communities in *S. niger* at Anchar to be comparatively species richer than the other 2 lakes. At Anchar, diversity indices were higher than at Dal and Manasbal. Although the data on component community richness of *S. niger* did not reveal any significant differences among the lakes, still the component communities in Manasbal were less species rich than the other 2 lakes. However, the estimation of Shannon's index for each host fish species did not lead to the separation of the lakes according to pollution gradient. The parasite species numbers detected in the investigated lakes present only slight differences, though the rates of prevalence are clearly higher in Anchar than in Dal and Manasbal. In contrast, the values for the Simpson's and Berger-Parker indices were consistently and markedly higher in Anchar compared to the data from the other 2 lakes. Thus, the study complements the findings of Poulin (1996) by providing evidence that when parasites are very abundant, the community would typically consist of a few well-represented (core) species and several rare species, but when parasites are not abundant no species is over-represented in the community.

The component community of *S. niger* was unusual in that it was overwhelmingly dominated by the digenean *P. cuticola* in Anchar and Dal. Particularly, *P. cuticola* was reported to be the most dominant and frequently occurring species when looking at both the abundance and number of worms found. Poulin (1996) argued that some species of parasites are always abundant due to intrinsically high rates of infection potential. In Manasbal *B. achieloganthi* contributed a greater proportion to component community of *S. niger*, but the dominance was not so overwhelming. Thus, the abundance of different species in the parasite communities investigated in this study are clearly unequal, and parasite communities are characterized by one or few dominant species and many subordinate species. Indeed, the abundance-versus-rank plots indicated a huge gap in abundance between the numerically dominant species in the parasite community and the next most common species in Anchar. In contrast, the differences in the relative abundance of the species in parasite communities of Dal and Manasbal were not so steep at all. Poulin *et al.* (2008) opined that differences in the rates of recruitment of individuals to the community can result in one or a few numerically dominant species and many rare ones. Considering that the recruitment rates are determined by the prevalence of infection in the intermediate hosts of helminths, the observed patterns in abundance among the lakes can be attributed to differences in the density of these first hosts that act as the source of infection for fish. Results from the present study also realize this expectation. Thus, an increase in the magnitude of the trophic status appears to relate positively to the steepness of the drop in the relative abundance seen on the abundance-versus-rank plots.

The relative ease with which a parasite may colonize a habitat depends on its life-cycle and availability

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of its intermediate hosts (Marcogliese and Cone, 1991). The density of intermediate hosts may reflect the degree of eutrophication because their abundance is closely related to the physico-chemical characteristics of an aquatic environment (Zander *et al.* 1999, 2000). The stress due to eutrophication leads to a high level of productivity and consequently, to changes in densities of primary consumers such as snails, and crustaceans, and detritivores like annelids which constitute the potential intermediate host guilds in the lakes (Shah, 2010). The specific intermediate hosts for *P. cuticola*, the planorbid snail *Gyraulus parvus*, and for *C. schizothoraxi*, the lymnaeid snail, *Lymnaea* spp. were more frequently detected at the Anchar as opposed to Dal and Manasbal (Shah, 2010). Furthermore, the population density of cyclopoid copepods and tubificid oligochaetes, the intermediate hosts of *B. achielognathi* and *A. oreini* respectively, has been recorded to be greater at Anchar than those at Dal and Manasbal (Shah, 2010). Given that transmission of parasites to a host is achieved by means of a free-living infective stage, the rate of encounter between the hosts and parasites will be influenced principally by their respective densities and their spatial distributions (Crofton, 1971; Anderson, 1978). This may be the reason why the abundance of infection was higher in Anchar. The trophic status of Manasbal is relatively lower than either Dal or Anchar and most intermediate hosts are low in density in this water body (Shah, 2010). Acanthocephalans were mostly rare in fish of the lakes. The barrier to their establishment may be due to a general absence or occurrence below threshold levels of amphipod intermediate hosts, necessary to sustain a viable worm population. It is quite possible that the lower prevalence of *P. kashmirensis* is due to smaller/ markedly reduced intermediate host populations (Shah, 2010). Thus, the transmission window for these parasites may be seasonally restricted too. However, the rare status of *N. manasbalensis* remains unclear as the necessary intermediate ostracod hosts are abundant in all the lakes (Shah, 2010). This discrepancy might be due to the fact that ostracods are not important items in the diet of fish (Yousuf *et al.* 2002) and are therefore less vulnerable to infection by *N. manasbalensis*. The rarity and occasional presence further suggests that these might have been the accidental infections.

The total number of species in component communities of lakes does not indicate a greater magnitude of change because the number of component species changed very little during the investigation period. In Anchar and Dal, all cestode and trematode parasites in *S. niger* proved to be component species (prevalence >10%) except *A. oreini* which was not a component species in the latter water body. In contrast, only *D. kashmirensis* and *B. acheilognathi* surpassed this limit in Manasbal. These differences may be the reflection of the differences in the proportion of allogenic and autogenic components in their respective component communities. Values of Shannon index were low throughout, and varied somewhat erratically at times, but within unexpectedly narrow limits and indicated a community of low and similar diversity. The addition of new species to the habitat increased richness, but had very little impact on community diversity as long as this was characteristically dominated so heavily by a single species. Therefore, Simpson's and Berger-Parker indices at component community level appeared to be the most satisfactory diversity measures available in this analysis. Both indices indicated an underlying constancy of community structure within each lake than any index and reflected a greater magnitude of differences among the lakes. Parasite species composition included a higher number of autogenic species (5) than allogenic species (2), but the latter group of parasites was more broadly distributed and represented a higher proportion of the total individual parasite count in Anchar. The allogenic species' dominance in number of individuals can be attributed to the lake's high productivity (the result of extensive eutrophication). This phenomenon has been reported in many eutrophic habitats (Wisniewski, 1958; Esch, 1971). The lower infestation potential in Manasbal compared with other two lakes which are no longer in a natural state can be associated with the differences in the nature of the lakes. Thus, the results are consistent with the conclusions of Wiśniewski (1958) and Esch (1971) in that fishes in eutrophic waters are more infected with larval forms compared to adult parasites. Additionally, the results of this study are also in line with the findings of Marcogliese and Cone (1991) that the proportion of larval forms is expected to be higher in shallow lakes than in deep lakes. The above discussion also confirms the findings of Zander *et al.* (2000) that the populations of invertebrate intermediate hosts of parasites with complex life-cycle change due to eutrophication, thus changing the concentration of parasites in vertebrate hosts that consume these invertebrates. Thus, in the light of these findings, it stands to reason that the presence or absence of parasites, along with customary methods of environmental monitoring like macroinvertebrate assessments and chemical analyses of sediment and water can be used to track pollution levels and indicate the health status of a lake ecosystem.

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