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ECOLOGICAL INVESTIGATION OF ZOOPLANKTON ABUNDANCE IN THE RIVER HARAZ, NORTHEAST IRAN: IMPACT OF ENVIRONMENTAL VARIABLES

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Abstract- The influence of physicochemical properties of Haraz river on its zooplankton composition and abundance were investigated at three sites for one year between August 2009 and July 2010. The present study records for the first time the aspects of zooplankton diversity and composition in relation to the physicochemical environment of the Haraz river. Only three groups of zooplankton were found: Rotifera with eighteen genera; Cladocera with nine and Copepoda with six genera. Rotifera was the predominant group (64.89%), followed by Cladocera (19.62%) and Copepoda (15.32%). Upstream, the abundance was 805 individuals/m^3, while it varied from 922 to 1126 ind/m^3 downstream. Alkaline pH and nutrients were the main environmental factors which affected zooplankton abundance in the river. Site variation in dominance, diversity, evenness and richness were calculated. The study revealed that the presence of certain species, such as *Lepadella* sp., *Mesocyclops* sp., *Polyarthra* sp. and *Brachionus* sp. is considered to be a biological indicator for eutrophication. The calculated Jack1 values of sites 1 to 3 were 7.624, 16.426 and 19.221, respectively. The Shannon-Wiever species diversity index (*H'*) values were also different for all the three sites viz., site 1 (1.992), site 2 (1.21) and site 3 (2.48). Simpson's dominance index (*H*) value was highest at site 1 (0.692), indicating maximum dominance, whereas at site 3 dominance was the lowest (0.227) and diversity was the highest. Overall, our results showed that changes in the water quality of the river Haraz have considerable effects on the composition of zooplankton assemblages that can potentially affect the functioning of these ecosystems.

Key words: Cladocera, Copepoda, Rotifera, Haraz river, physicochemical factors, zooplankton.

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INTRODUCTION

The circulation of aquatic organisms, and particularly plankton, has long been known to be heterogeneous. Spatial heterogeneity is a general feature in all ecosystems and is the consequence of many cooperating physical and biological processes (Pinel-Alloul, 1995). Zooplankton species are cosmopolitan in their clean freshwater habitat and are also found in industrial and municipal wastewaters. The study of freshwater fauna, mainly zooplankton, even of a particular area is widespread and convoluted due to environmental, physical, geographical and chemical differences involving ecological, extrinsic and essential aspects. While the distribution of biodiversity worldwide can be explained in terms of the comparatively small number of spatial prototypes such as latitude, altitude or habitat size, understanding how these extrinsic drivers influence diversity remains one of the most important intellectual challenges to ecologist and biogeographers (Gaston, 2000). The species composition, distribution, diversity and relative abundance of zooplankton in an aquatic ecosystem could have an important impact on fisheries and public health of the river and its users. The typical zooplankton assemblage of an aquatic ecosystem is commonly comprised of protozoa, Rotifera, Copepoda and Cladocera (Rocha et al., 1999). This assemblage frequently differs in diversity and abundance from river to river, from site to site within each river, from geographical region to region and also with time, and it is structured by fish predation, competition, aquatic macrophytes (Jackson and Schmitz, 1987) and physical, chemical and biological aspects (Sampaio et al., 2002). The objective of this paper is to investigate the species composition and community structure of the zooplankton of the Haraz river in relation to physicochemical factors of the river.

MATERIAL AND METHODS

Study area

The Haraz river basin is located in the Mazandaran province and northern region of Iran (Fig. 1). It lies between longitude of 35°52′ and 45°5′ and latitude of 35°45′ and 36°15′. The Haraz river is 185 km long with a discharge of 940 × 106 m3/y (in 2009). The width of the river ranges from 50 to 500 m at different locations. The catchments area of the river is about 4,060 km^2 with an average precipitation of 832 mm/y (Karbassi et al., 2008). The Haraz river originates from the Alborz mountain ranges and flows into the southern coast of the Caspian Sea (Keramat-Amirkolaie, 2008). The Haraz river is a major source for agriculture activities, particularly in its downstream basin areas. The river is fed by a number of tributaries at the different reaches; the main ones are Namarestagh, Shirkola, Razan and Chelorud. The Haraz basin has specific geological characteristics affecting the river water quality. Mainly, the central and southern parts of the basin contain many giant and super giant Paleozoic and Mezozoic lime, dolomite and shale deposits. Frequent coal layers are observed, especially in the southern parts of the basin. This area has been a rich source of minerals from times immemorial. About 45 mines (coal, limestone, sand and gravel, etc.) have been operational for the last eight decades. Having been formed by magmatic activities through the volcanic deposits of the south-eastern areas, hydrothermal springs are found in the central parts of the basin. Sulfide ores exposed to atmospheric oxygen and moisture can undergo a series of reactions, producing metals (Baba and Gungor, 2002), which are carried downstream by the river. Furthermore, hydrothermal springs may also facilitate the entrance of toxic metals into the river stream. In addition, towards the estuary, the density of urban, industrial and agricultural land-use increases and consequently the river receives the discharge of industrial, agricultural and urban waste. Fig. 1 shows the location map of the Haraz river water basin in Iran and Mazandaran province, as well as the sampling sites. Site 1 is from the upstream side and lies in a rural area. Site 3 is from the downstream side at the beginning of the urban area that receives water from municipal wastewater.

Water sampling

Sampling was done from three sites (Fig. 1) during four seasons, viz., winter, spring, autumn and summer. The results have been summarized as an annual average**.** Samples were collected in sterile capped containers following the method as described by APHA (1998). To avoid contamination, disposable gloves washed in 1 N HCl were worn during water sampling. Sampling bottles were kept in large, airtight plastic ice-cold containers at 4°C and were transported to laboratory within 6 h of their collection for further processing. Water samples were analyzed for the level of pH, turbidity, electrical conductivity (EC), total dissolved solids (TDS), total alkalinity (TA), total hardness (TH), chemical oxygen demand (COD), biochemical oxygen demand (BOD), dissolved oxygen (DO), sulphate (SO_4), nitrate (NO_3), calcium (Ca), magnesium (Mg) and phosphate (PO_4) by following the method as described by APHA (1998).

Zooplankton sampling

Zooplankton samples were collected using a 25cm diameter zooplankton net with a 76 μm mesh size seasonally between August 2010 and July 2010. The net was towed vertically over a distance of 2 m on the water surface due to the shallowness of the river,

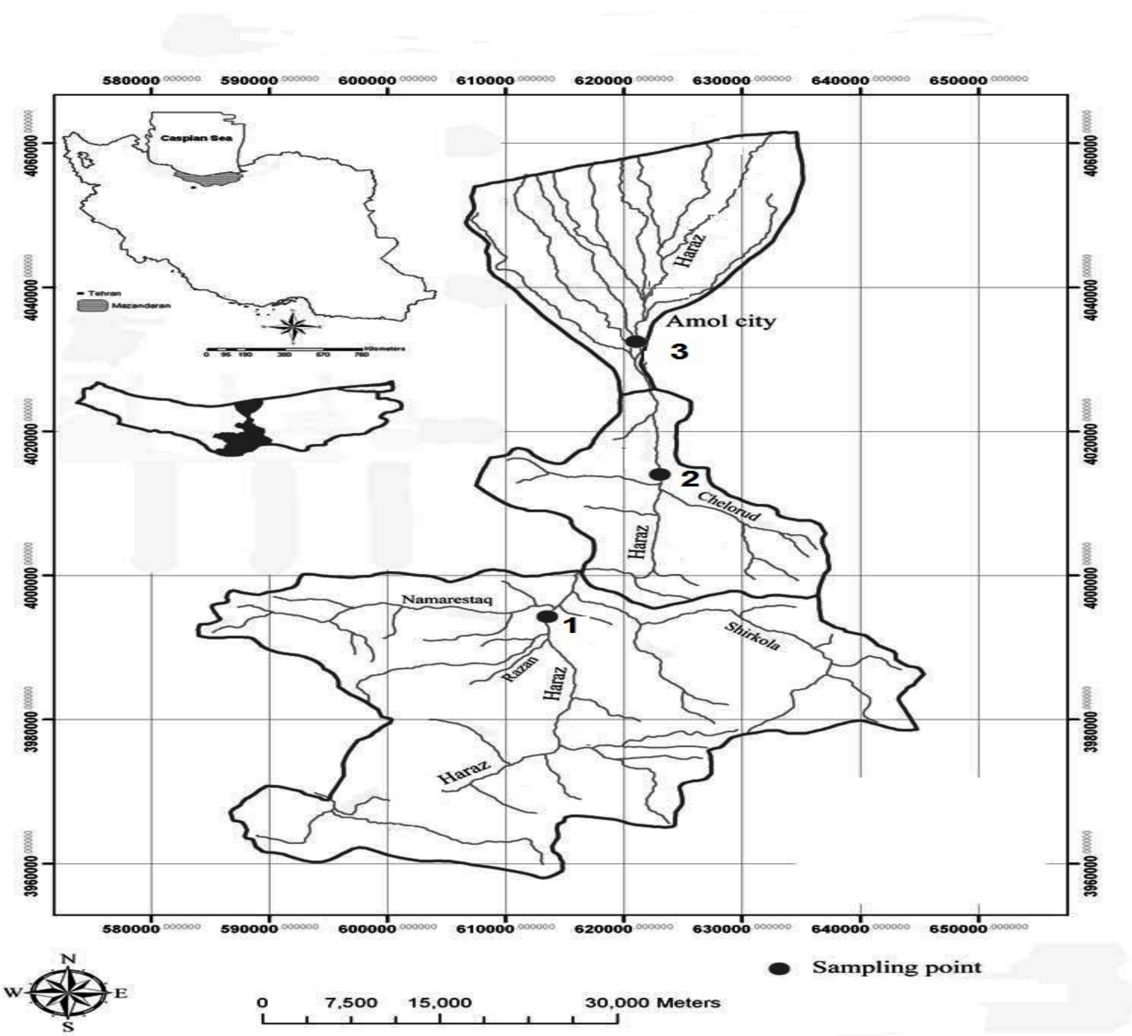

Fig. 1. Map of the study area and surface water quality sampling stations in Haraz river basin.

and the samples were collected into 50ml bottles and preserved in 10% formalin. A 5 ml subsample was taken for identification under the microscope after the preserved sample had been homogenized. Identification was done using the descriptive keys of Han (1978), Prescott (1982) and Edmonson (1959). In order to assess the community structure, the indices of species diversity (*H*'), Margalef's richness index (*D*), Simpson's dominance index (*S*) and Pielou's evenness index (*J*) were used. Numerical estimations of the zooplankton were done using the drop method of Margalef (1976). Abundance of zooplankton was estimated as individual/m^3 of the original sample using the equation (Boyd, 1981; APHA, 1998):

$$D = \frac{T(1000 \times Vc)}{AN \times Vs}$$

Where:
D = Density of plankton (individual /mil)
T = Total number of plankters counted
A = Area of grid in mm^2
N = Number of grids employed
1000 = Area of counting chamber in mm^2
Vc = Volume of concentration
Vs = Volume of sample

RESULTS AND DISCUSSION

Physicochemical factors

The results of the investigation of the physicochemical parameters are given in Table 1. The temporal and spatial variations in pH (6.2-8.2) indicate a slightly alkaline water. The higher pH at site 1 could be due to bicarbonates and carbonate of calcium and magnesium in the water. Downstream the water shows higher pH values compared with the upstream water, which may be due to the mixing and dissolution of basic cations with runoff water along the course of the river. Low pH is frequently caused by a high concentration of carbon dioxide from the atmosphere (Neal et al., 1998).

The DO value for the Haraz river ranged between 2.3 to 8.1 mg/l, as shown in Table 1. Low DO levels below 4 mg/l were detected at sites 2 and 3. Site 3 is a location which collects all the municipal wastewater pollution and site 2 collects agricultural wastewater. Oxygen levels may drop to such hazardously low levels that oxygen-dependent animals in the water, such as fish, die. The BOD value indicates organic pollution in the aquatic systems, which adversely affects the river water quality and biodiversity. In the Haraz river, BOD ranged from 15.3 to 125.12 mg/l at different sites. Due to the mixing of wastewater from city and industries, the BOD values increased from site 2 onward. Comparatively, lower BOD at the upstream site (site 1) than at the other downstream sites clearly suggested the anthropogenic stress of the Haraz river. The high values of BOD indicated the presence of an excess of biodegradable organic matter from the municipal and agricultural sewage. Similarly, Kannel et al. (2007) has reported that water pollution in urban areas is usually related to untreated municipal sewage and irrigation activities. COD varied from 14.3 to 89.14 mg/l at the different sampling sites. The high values of COD indicate water pollution which is related to sewage effluents discharged from town, industry or agricultural practices. The electrical conductivity (EC) of the Haraz river water was significantly different among the sampling sites, varying from 198 to 411 μS/cm. High conductivity at site 3 indicates the mixing of sewerage in the river water. Lower conductivity in the upstream water may be due to the dilution of agricultural and industrial runoffs. However, the high conductivity of the Haraz water corresponded to the highest levels of dominant ions due to originally higher rock soil dissolution. These findings are consistent with the results of other researchers (Alam et al., 2007; Girija et al., 2007).

Alkalinity is important for zooplankton and aquatic life as it buffers against rapid pH changes (Capkin et al., 2006). The mean TA was in the range 197–482 mg/l. Total alkalinity increased downstream as compared with upstream river flow, which might be attributed to the mixing of alkaline salts with runoff water. The results are the same as for the assessment of Brahmaputra river water quality (Girija et al., 2007). Turbidity of the Haraz river fluctuated between 3.1 to 59.10 NTU. A higher value of turbidity was found in site 3 and the lower values were observed in site 1. This higher value was possibly due to the mixing of domestic sewerage water and agricultural effluents in the river. Khadse et al. (2008) reported similar patterns of spatial variations in turbidity whilst studying the water quality of the river Kanhan. In the present investigation, the total dissolved solids content fluctuated between 197 to 391 mg/l, with a higher value of TDS in site 3 and a lower value in site 1. Similar findings have been reported by Garg et al. (2010). The amount of total hardness of the Haraz river varies from 102-421 mg/l (Table 1). The highest values were found at site 3, while the minimum concentrations of hardness were found at site 1. Phosphorus is a nutrient that can support the growth of certain aquatic plants and can cause algal blooms (Donnelly et al., 1998). Aquatic ecosystems which have phosphorus concentration exceeding 0.02 mg/l are termed eutrophic. Eutrophication results in changes in vegetation and animal communities, including a large increase in the biomass of filamentous algae and macrophytes, which together with the sediment can have a considerable influence on the oxygen resources of a river (Bellos and Sawidis, 2005; Rutherford et al., 1991). The phosphorus concentration of the Haraz river water differed significantly among the sampling sites, varying from

Table 1. Mean and standard deviation of the physicochemical parameters measured at the study sites of Haraz river

Parameters	Site 1			Site 2			Site 3		
	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD
Water Temp. (°C)	12.2-28.9	23.6	4.1	12.6-29.2	23.8	4.6	12.9-31.3	24.1	3.9
pH	6.2-7.9	7.92	0.51	6.5-7.9	7.2	0.31	7.8-8.2	6.8	0.42
DO (mg l^{-1})	4.6-8.1	6.78	1.98	2.3-6.1	4.12	1.98	3.2-8.31	5.98	2.05
BOD (mg l^{-1})	15.3-80.31	51.36	23.31	21.20-97.11	58.36	23.17	30.14-125.12	80.14	29.14
COD (mg l^{-1})	14.3-65.3	46.09	14.57	19.12-70.41	48.17	15.09	25.36-89.14	41.06	14.61
Conductivity (μScm^{-1})	198-402	325.14	43.52	221-396	281.31	44.31	258-411	345.21	48.11
Total Alkalinity (mg l^{-1})	211-425	358.09	81.12	197-441	398.12	75.36	205-482	354.31	80.23
Turbidity (NTU)	5.1-42.2	21.05	12.04	3.1-48.2	25.30	13.14	3.9-59.10	30.12	14.10
TDS (mg l^{-1})	194-305	284.16	68.14	198-314	281.14	48.42	223-391	298.47	46.20
Total Hardness (mg l^{-1} $CaCO_3$)	102-411	265.14	69.28	141-385	287.36	70.12	168-421	321.25	81.36
PO_4^{3-} (mg l^{-1})	0.19-0.69	0.49	0.09	0.68-1.04	0.78	0.21	0.98-1.14	0.91	0.32
SO_4^{2-} (mg l^{-1})	7.8-19.2	12.09	2.96	4.4-21.31	14.31	4.12	5.9-29.34	15.14	5.69
NO_3 (mg l^{-1})	1.51-12.05	6.18	3.47	3.46-18.47	11.03	5.31	4.06-24.32	12.09	6.06
Ca^{2+} (mg l^{-1})	6.14-29.11	19.78	7.06	9.24-32.15	22.14	4.99	13.14-42.13	26.34	6.45
Mg^{2+} (mg l^{-1})	2.01-11.14	7.61	1.54	1.41-10.98	6.11	2.36	2.02-15.61	7.91	3.16

0.19 to 1.14 mg/l. The higher concentrations of phosphorus observed at the urban area (site 3) are related to municipal wastes. The association of point source discharges with prominent levels of phosphate, especially in relation to urban areas, is consistent with many studies. Higher phosphorus concentration is the result of detergents and industrial wastes (Soltan, 1991) together with agricultural and human waste input in an urban river. Sulphate and nitrate are important parameters of river water showing the pollution and anthropogenic load in the water. In the Haraz, SO_4 and NO_3 ranged between 4.4-29.34 and 1.51-24.32 mg/l, respectively, at the different sampling sites (Table 1). The highest concentrations of nitrate were found in the urban areas (site 3). This was attributed to municipal sewage and industrial effluents through highly polluted urban sites. Low nitrate and sulphate concentrations in the rural areas indicated that the major source of sulphate and nitrates were not agricultural runoff, but the sewage effluents in the urban areas. Kannel et al. (2007) reported that high levels of nitrate indicates numerous sources of sewage and agricultural runoffs.

The calcium and magnesium content in the river water ranged between 6.14-42.13 and 1.41-15.61 mg/l, respectively. The magnesium concentration was found to be lower than the calcium concentration in all the sites. Calcium-to-magnesium ratios in the downstream sites are higher compared to the upstream site which might be due to the higher calcium content in city sewage. High carbonate content causes calcium and magnesium ions to form insoluble minerals, leaving sodium as the dominant ion in the solution. This alkaline water could intensify sodic soil conditions (Bauder et al., 2006).

Zooplankton species composition

Forty two species of zooplankton were identified from the Haraz river (Table 2). They belong to Rotifera (twenty five), Cladocera (ten species) and Copepoda (seven species). The Rotifera (25 to 470 organisms/m^3) constituted the largest group making up 64.89% of the zooplankton population; this was followed by Cladocera (19.62%) with organisms ranging between 45 to 112 organisms/m^3 and

Table 2. List of zooplankton species obtained at different sites along Haraz river

Zooplankton species	Site 1	Site 2	Site 3
Rotifera			
Ascomorpha ecaudis (Perty)	+	-	+
Asplanchna priodonta Gosse	-	-	+
Brachionus angularis Gosse	-	+	+
B. calyciflorus Pallas	-	+	+
B. quadridentatus f. *brevispinus* (Ehrb.)	+	-	+
Cephalodella gibba (Ehrb.)	-	+	-
C. sp.	+	+	+
Colurella adriatica (Ehrb.)	-	+	+
C. uncinata (O.F.M.)	-	+	-
Dicranophorus uncinatus (Milne)	+	+	-
Euchlanis deflexa (Gosse)	-	-	+
Kellicottia longispina (Kell.)	-	+	+
K. quandrata (Müller)	+	-	+
Lecane bulla (Gosse)	+	+	-
L. lunaris (Ehrb.)	-	-	+
Lepadella ovalis (Müller)	-	+	-
Lophocharis salpina (Ehrb.)	+	-	-
Notholca foliacea (Gillard)	-	+	-
Platyias quadricornis (Ehrb.)	-	-	+
Polyarthra vulgaris Carl.	+	+	+
P. major (Burck.)	+	+	+
Scaridium longicaudum (O.F.M.)	-	-	+
Sinantherina sp.	+	+	-
Trichocerca elongata (Gosse)	-	+	+
Trichotria tetractis (Ehrb.)	-	-	+
Cladocera			
Alona guttata Sars	+	-	-
Biapertura affinis (Leydig.)	-	+	-
Bosmina longirostris (O.F.Müller)	+	+	-
Ceriodaphnia pulchella Sars	-	-	+
Daphnia cucullata Sars	-	+	+
Grimaldina brazzai Richard	+	+	-
Ilyocryptus sordidus Lievin	+	-	+
Macrothrix goeldii Richard	-	+	+
Macrothrix spinosa King	-	+	-
Scapholeberis kingi Sars	+	+	-
Copepoda			
Cyclops sp.	+	+	+
Eudiaptomus gracilis Sars	-	+	+
Heliodiaptomus contortus Gurney	+	+	+
Megacyclops sp.	+	+	-
Mesocyclops leuckarti Claus	-	+	-
Paracyclops fimbriatus Fischer	+	-	+
Trophocyclops prascinus Fischer	-	+	+

Table 3. Zooplankton composition and abundance in site 1 of Haraz river

Class	Genus	Organism /m^3	Species % in class	Species % in total zooplankton	Class % in total zooplankton
Rotifera	*Ascomorpha*	140	26.02	17.39	66.83
	Asplanchna	59	10.96	7.32	
	Brachionus	120	22.30	14.90	
	Cephalodella	35	6.50	4.34	
	Dicranophorus	28	5.20	3.47	
	Kellicottia	38	7.06	4.72	
	Lecane	41	7.62	5.09	
	Lophocharis	25	4.64	3.10	
	Polyarthra	21	3.90	2.60	
	Sinantherina	31	5.76	3.85	
Total		538	100	66.83	
Cladocera	*Alona*	46	30.66	5.71	18.36
	Bosmina	33	22	4.09	
	Grimaldina	23	15.33	2.85	
	Ilyocryptus	26	17.33	3.22	
	Scapholeberis	22	14.66	2.73	
Total		150	100	18.63	
Copepoda	*Cyclops*	43	36.75	5.34	14.53
	Heliodiaptomus	33	28.20	4.09	
	Megacyclops	21	17.94	2.60	
	Paracyclops	20	17.09	2.48	
Total		117	100	14.53	
Grand Total		805			100

Copepoda (15.32%), which had a density between 35 to 124 organisms/m^3. The genus Brachionus dominated the zooplankton genera (25.89%) and was also the dominant genus among the Rotifera making up 25.89% in the group. The genus Daphnia recorded the highest number among the Cladocera making up 20.40% of the total zooplankton, while the genus Cyclops constituted 4.43% of the total zooplankton was the dominant genus among the class Copepoda. The genus Ilyocryptus, a cladoceran, was the least abundant comprising only 1.61% of the zooplankton population of the Haraz river (Table 3-5). A total of 2793 organisms/m^3 of zooplankton was recorded in the river (Table 6).

The zooplankton assemblage in the Haraz river was attributed to several biotic and abiotic factors interacting together. These include alkalinity, nutrients and food availability. The 33 genera of the zooplankton found, consisting of Rotifera (eighteen), Cladocera (nine) and Copepoda (six), could not be described as highly diverse. The zooplankton genera found in the present study agrees with the observations of Rocha et al., (1999) about zooplankton assemblages in aquatic ecosystem. The dominance of Rotifera and the genus Brachionus was not unexpected as both the latter and former have been reported by Mustapha (2009), Akin-Oriola (2003) and Mustapha and Omotosho (2006) as the most dominant zooplankton group in aquatic ecosystems. The high population density of the rotifers could be attributed to their parthenogenetic reproductive patterns and short developmental rate under favorable conditions (Pouriot et al., 1997), their morphological variations called cyclomorphosis and adaptations (Wetzel, 2001), and their ability to feed on different food types. The dominance of rotifers was due to its preference for warm waters as highlighted by

Table 4. Zooplankton composition and abundance in site 2 of Haraz river

Class	Genus	Organism /m³	Species % in class	Species % in total zooplankton	Class % in total zooplankton
Rotifera	*Asplanchna*	66	12.35	7.15	57.91
	Brachionus	140	26.21	15.18	
	Cephalodella	48	8.98	5.20	
	Colurella	28	5.24	3.03	
	Dicranophorus	38	7.11	4.12	
	Kellicottia	41	7.67	4.44	
	Lecane	26	4.86	2.81	
	Lepadella	28	5.24	3.03	
	Notholca	30	5.61	3.25	
	Polyarthra	42	7.86	4.55	
	Sinantherina	25	4.68	2.71	
	Trichocerca	22	4.11	2.38	
Total		534	100	57.91	
Cladocera	*Biapertura*	46	21.19	4.98	23.53
	Bosmina	49	22.58	5.31	
	Daphnia	23	10.59	2.49	
	Grimaldina	36	16.58	3.90	
	Macrothrix	31	14.28	3.36	
	Scapholeberis	32	14.74	3.47	
Total		217	100	23.53	
Copepoda	*Cyclops*	29	16.95	3.14	18.54
	Eudiaptomus	25	14.61	2.71	
	Heliodiaptomus	34	19.88	3.68	
	Megacyclops	25	14.61	2.71	
	Mesocyclops	35	20.46	3.79	
	Trophocyclops	23	13.45	2.49	
Total		171	100	18.54	
Grand Total		922			100

Dumont (1983) and Segers (2003). The dominance of Brachionus is an indication that the Haraz river is eutrophic and their abundance was due to the presence of high levels of organic matter in the river (Matsumura-Tundisi, 1999). The relatively low abundance of Cladocera and copepods was a result of the hydrodynamics of the river such as low water volume, short residence time, relative old age of the river and its morphometry.

The highest population of the two groups occurred at site 2 which was due to the presence of food (phytoplankton) on which they graze and the high transparency of the zone. High clay content and silt turbidity resulting in low transparency was responsible for the low population of crustacean zooplankton in site 2. The effect of this caused juvenile mortality of the zooplankton and suppressed their growth through food availability. This suppression could have encouraged the rotifer population to dominate. Kirk and Gilbert (1990) have noted this type of scenario in a tropical reservoir. The low genera abundance of cladocerans and copepods has also been documented in other water bodies such as Lake Cubhu in South Africa (Martin and Cyrus, 1994), the Ogun and Ona rivers (Akin-Oriola, 2003) and the Niger-Sokoto river (Jeje and Fernando, 1992). The predominance of *Daphnia* among the cladocerans could be because of

Table 5. Zooplankton composition and abundance in site 3 of Haraz river

Class	Genus	Organism/m^3	Species % in class	Species % in total zooplankton	Class % in total zooplankton
Rotifera	*Ascomorpha*	120	15.52	10.65	68.65
	Asplanchna	70	9.05	6.21	
	Brachionus	210	27.16	18.65	
	Cephalodella	59	7.63	5.23	
	Colurella	32	4.13	2.84	
	Euchlanis	38	4.91	3.37	
	Kellicottia	65	8.40	5.77	
	Lecane	21	2.71	1.86	
	Platyias	32	4.13	2.84	
	Polyarthra	36	4.65	3.19	
	Scaridium	28	3.62	2.48	
	Trichocerca	33	4.26	2.93	
	Trichotria	29	3.75	2.57	
Total		773	100	68.65	
Cladocera	*Ceriodaphnia*	46	21.69	4.08	18.82
	Daphnia	49	23.11	4.35	
	Ilyocryptus	89	41.98	7.90	
	Macrothrix	28	13.20	2.48	
Total		212	100	18.82	
Copepoda	*Cyclops*	52	36.87	4.61	12.52
	Eudiaptomus	20	14.18	1.77	
	Heliodiaptomus	26	18.43	2.30	
	Paracyclops	21	14.89	1.86	
	Trophocyclops	22	15.60	1.95	
Total		141	100	12.52	
Grand Total		1126			100

its large body size which enables it to graze on large quantities and diverse forms of phytoplankton. The high *Daphnia* population occurred due to their effective grazing on rotifers. The density and biomass of cladocerans were primarily determined by food supply. Although the genus *Cyclops* was the dominant genus among the copepods, its relatively low abundance in the river could be described as a good sign. The low population of the genus could be due to their slow reproduction, growth and renewal rate. The absence of parthenogenetic forms of copepods might be responsible for their low population density. The high population density and biomass of zooplankton in the downstream area (site 3) was traced to the high population of the phytoplankton food source which were highly abundant within the river during the different seasons. According to Rocha et al. (1999), an increase in primary production (phytoplankton) tends to be followed by an increase in zooplankton number and biomass. Achembach and Lampert (1997) have emphasized these factors as being responsible for zooplankton biomass reduction. Food resource (Carpenter et al., 1987), the ability to adapt to food conditions and less predation (Rosemond et al., 1993), may be the reasons for the significant abundance of rotifers, Cladocera and Copepoda in the aquatic ecosystem.

The absence of some genera such as *Asplanchna, Ceriodaphnia, Euchlanis* and *Trichotria* in sites 1 and 2 could have occurred as a result of patchiness or dispersal. Dispersal has been noted to play a major role in structuring zooplankton populations and communities (Shurin and Havel, 2002). Generally,

Table 6. Zooplankton composition and abundance of Haraz river

Class	Genus	Organism/m^3	Species % in class	Species % in total zooplankton	Class % in total zooplankton
Rotifera	*Brachionus*	470	25.89	16.82	64.89
	Ascomorpha	260	14.32	9.30	
	Asplanchna	195	10.74	6.98	
	Kellicottia	144	7.93	5.15	
	Cephalodella	142	7.82	5.08	
	Polyarthra	99	5.45	3.54	
	Dicranophorus	66	3.63	2.36	
	Colurella	60	3.30	2.14	
	Lecane	58	3.19	2.07	
	Sinantherina	56	3.05	2.00	
	Trichocerca	55	3.03	1.96	
	Euchlanis	38	2.09	1.36	
	Platyias	32	1.76	1.14	
	Notholca	30	1.65	1.07	
	Trichotria	29	1.59	1.03	
	Lepadella	28	1.54	1.00	
	Scaridium	28	1.54	1.00	
	Lophocharis	25	1.37	0.89	
Total		1815	100	64.89	
Cladocera	*Daphnia*	112	20.40	4.01	19.62
	Bosmina	82	14.93	2.93	
	Grimaldina	59	10.74	2.11	
	Macrothrix	59	10.74	2.11	
	Scapholeberis	54	9.83	1.93	
	Alona	46	8.37	1.64	
	Biapertura	46	8.37	1.64	
	Ceriodaphnia	46	8.37	1.64	
	Ilyocryptus	45	8.19	1.61	
Total		549	100	19.62	
Copepoda	*Cyclops*	124	28.90	4.43	15.32
	Heliodiaptomus	93	21.67	3.32	
	Megacyclops	46	10.72	1.64	
	Trophocyyclops	45	10.48	1.61	
	Eudiaptomus	45	10.48	1.61	
	Paracyclops	41	9.55	1.46	
	Mesocyclops	35	8.15	1.25	
Total		429	100	15.32	
Grand Total		2793			100

the zooplankton community of the Haraz river was dominated by rotifers, which due to their short generation time and their high reproductive rate (Allan, 1976), dominate in rivers (Klimowicz, 1981; Pourriot, et al., 1982; Saunders and Lewis, 1988). Among the species identified as indicators of eutrophication in this river as well as in other regions, the rotifer *B. calyciflorus* stands in its great tolerance to extremely

Table 7. Different indices to comment on the community structure of the study sites

Diversity indices	Site 1	Site 2	Site 3
Shannon-Wiever Species Diversity Index $H' = -\sum_{i=1}^{S} P_i \text{ h } P_i$	2.361	1.21	2.48
Pielou's Evenness Index $J = H' / \text{h } S$	0.736	0.924	0.814
Species Number Estimate $Jack1 = S + r_1 (n - 1)/n$	19.221	16.426	7.624
Margalef's Richness Index $D = (S - 1) / \text{h } N$	3.012	2.615	1.821
Simpson's Dominance Index $H_{SIMP} = \sum_{i=1}^{S} (P_i)^2$	0.692	0.712	0.227

Where S = observed number of species; P_i = Proportional abundance of species i; n = number of individuals per species; N = total number of individuals per sample; r_1 = occurrence of species with minimum density.

eutrophic environments (Sládecek, 1983) and to high conductivity (Berzins and Pjeler, 1989). *Polyarthra vulgaris* occurred throughout the year. Slàdeček (1983) considered it as a permanent inhabitant of all types of fresh water, while Sharma and Pant (1985) regarded it as a good indicator of eutrophication. According to our results, the factors that explained the greatest percentage of the variations were nitrogen and phosphorus (also noted for the river Po (Ferrari et al., 1989)), as well as water pH and oxygen which are also known to influence zooplankton abundance (Allan, 1976; Wetzel, 1983). Considering the differences found between the three sites, it seems that the distribution of zooplankton along the Haraz river follows the general pattern noted along the courses of other rivers, with a higher abundance and more diverse species composition downstream (Krzeczkowska-Woloszyn, 1985; Brown, et al., 1989). In the case of the Haraz river, the downstream site is also affected by the water bodies connected to the river, such as reservoirs, which may contribute to the species composition and abundance (Zarfdjian, et al., 2000; Pourriot, et al., 1997). The abundance of zooplankton with nitrate and phosphate may not necessarily be direct related to the zooplankton utilizing the nutrients, but could be attributed to the dependence of the phytoplankton on these nutrients. Alkaline pH was also found to favor zooplankton growth and abundance in the river, as seen from the direct relationship with pH. Byars (1960) reported that zooplankton prefer alkaline waters. Both conductivity and total dissolved solids promoted high zooplankton growth and abundance. This agrees with the findings of Hujare (2005).

The zooplankton assemblage of the Haraz river was linked to the soft nature of the water which they prefer as observed in the direct relationship with both calcium and magnesium ions which were the contributors of the low hardness. This type of relation has been reported by Hulyal and Kaliwal (2007) in the Almati reservoir in India. The zooplankton community composition of the river also showed the Haraz river to be productive and able to support diverse species and populations of fish. The assemblage was strongly influenced by the physico-chemical factors. Alkaline pH, food abundance and nutrients were some of the factors that could limit zooplankton growth, composition and abundance in the aquatic ecosystem. Maintenance of good water quality in the river will enhance the zooplankton community structure and population dynamics and this will be of great advantage for fish production in the river since the energetic trophic foundations for fish would have been well established.

Zooplankton community structure analysis

The variations in dominance, diversity, evenness, richness and other indices of community structure are given in Table 7. For this purpose, species richness was employed to resample the observed species and to relate the estimated species richness to a higher sample size. The species number estimate values calculated for the three sites were as follows: site 1, 19.221; site 2, 16.426 and site 3, 7.624. Therefore, the value was lowest for the most polluted sampling point (site 3) and highest for the upstream point (site 1). Pielou's index of evenness (*J*) was highest in site 2 (0.924) followed by site 3 (0.814) and site 1 (0.736). Simpson's dominance index (*H*), which is also based on proportional abundance like *H'*, showed quite contrasting values to those for *H'*. Simpson's dominance index value was highest for site 2 (0.712) indicating maximum dominance at the site with minimum diversity, as reflected by the *H'* value. In contrast, dominance was lowest at site 3 (0.227) where diversity was maximum (2.48).

Although both Shannon measures and Simpson's index consider the proportional abundance of species, *H'* is more sensitive to rare species and the dominance index puts more emphasis on the common species. Margalef's richness index (*D*), which considers both abundance and species numbers, varied between 1.821 and 3.012. The highest (*D)* value of 3.012 was calculated at site 1, followed by site 2 (2.615) and site 3 (1.821) (Table 7). All these sites harbored a good number of zooplankton species. The Shannon index of general diversity more than doubled from site 2 (1.21) to site 3 (2.48). The Shannon diversity index appeared to be an efficient tool to evaluate the structural complexity of the microcrustacean assemblages. A consistent diversity decrease in site 2 was observed, and certainly it is related to two different factors: very low water retention time and eutrophication process, respectively. Evenness and richness indices also showed the same trend, indicating a gradual improvement of the abiotic environment from site 2 through to site 3.

However, the density and diversity of the planktonic organisms, even at the distant sites of 2 and 3, were significantly lower compared to the reports from clean uncontaminated waters (Michael, 1968; Sharma, 1992). This definitely indicated the presence of a stressful physicochemical environment even at the final discharge site of the river where there was considerable natural abatement of most of the toxicants.

CONCLUSION

The zooplankton composition of the Haraz river showed the river to be productive and capaable of supporting diverse species and populations of fish. The assemblage was strongly influenced by the physicochemical factors which showed the water quality to be good, according to APHA (1998). The alkaline pH, food abundance and nutrients were some of the factors that could limit zooplankton growth, composition and abundance in the aquatic ecosystem. Maintenance of good water quality in the river will enhance the structure of the zooplankton community and population dynamics. This is of great significance for fish production in the river since the energetic trophic foundation that supports fish are is well-established.

Despite the presence of a high nutrient load, other different chemical factors might have been responsible for checking the excess growth of autotrophs, leading to eutrophication. Nogueira (2001) reported that the index of eutrophic waters is above 15 species and that its abundance is considered as a biological indicator for eutrophication. *Brachionus calyciflorus* was frequently observed at all sampling sites in the Haraz river. This species is considered to be an indicator of eutrophication (Sampaio, et al., 2002). The results indicate that the Haraz river water has already reached the stage of eutrophication. Nogueira (2001) reported *Brachionus calyciflorus* to be an indicator of sewage and industrial pollution. This study concluded that the water of Haraz river is highly polluted by the direct contamination of sewage from industrial and agricultural activities. Therefore, the water body has to be preserved for its intended use, and a sustainable and holistic management planning is necessary for the conservation of this river.

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