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PHYSICO-CHEMICAL AND BIOLOGICAL CHARACTERISTICS OF SARABS (SPRING POOLS) IN THE KERMANSHAH PROVINCE OF IRAN*

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Abstract– Sarabs (spring-fed pools) are an important natural freshwater resource in Iran where they are used for potable, agricultural and recreational purposes. A survey of 17 Sarabs was undertaken in the Province of Kermanshah to obtain data on their water quality and biology which would help inform future management of these multifunctional resources. These Sarabs differed greatly in size (50-30000m^2 surface area) and were situated at altitudes of between 622 and 1697 m above sea level. The average dissolved oxygen content and pH of the water was between 4.5 and 10mg O_2/l, and 6.95 and 7.6 respectively. The Sarabs differed particularly in their dissolved solids content from 100µS/cm (detectable limit) to 600µS/cm. Four Sarabs appeared to be polluted by biodegradable organic matter. An Ekman grab was used in June 2003 to sample the benthic macroinvertebrate faunas. Average population densities, based on the numbers of animals retained by a 600µm mesh sieve, were between 2068 and 21531/m^2. Fifty-eight taxa (mainly genera) were identified. Of these, 65% were molluscs, oligochaetes and chironomids. There was relatively little similarity amongst the faunas of the individual Sarabs, but seven taxa occurred in more than half those sampled: *Gammarus pulex*, *Tanytarsus*, *Eukiefferiella*, *Tubifex*, *Erpobdella*, *Viviparus* and *Dugesia*. The observed distribution of the macroinvertebrates recorded in this survey was largely unexplained by the water quality variables (COD, BOD_5, DO, electrical conductivity, pH) measured. Taxon richness for the individual Sarabs differed from 5 to 21. Larger Sarabs tended to support more taxa than the smaller Sarabs.

Keywords – Sarabs, spring pools, limnocrenes, macroinvertebrates, Iran

1. INTRODUCTION

Freshwater is an increasingly scarce resource throughout most of the world and is likely to become evermore so as global warming and the growth in human population continue to take effect. It is, therefore, necessary for our present freshwaters to be managed efficiently and sustainably to provide the water needed for agricultural, industrial and potable use. It is increasingly recognized that for economic, aesthetic, moral and biological reasons [1], this management must have as little adverse impact as possible on the natural environment.

In central and western Iran, despite an average annual rainfall (1971-1991) of between 400mm (western plains) and 900mm (more mountain areas), a combination of seasonality and Karstic geology means that natural surface water is scarce and the areas arid. The most important sources of water are the Sarabs, which are spring-fed pools (limnocrenes) formed where underground water emerges. Although spring pools have been investigated previously in various parts of the world, principally Europe and North America [2, 3], there is little information about those that occur in the Middle East. As the management of this resource can only be achieved efficiently and benignly if the structure and dynamics of the system are

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properly understood, the survey described in the present paper was undertaken to provide a description of the physico-chemistry and biology of these pools as a contribution to this understanding.

2. METHODS

The survey was carried out in the Kermanshah Province of Iran (Fig.1) where more than 60 Sarabs have been recorded. For our investigation, 17 of these were selected (Fig.1, Table 1) on the basis of permanency, accessibility, floral diversity, and distribution across the Province. The smallest Sarab we sampled had a surface area of $50m^2$, while the largest had an area of $30000m^2$. They were at altitudes between 622 and 1697m above sea level (Table 1).

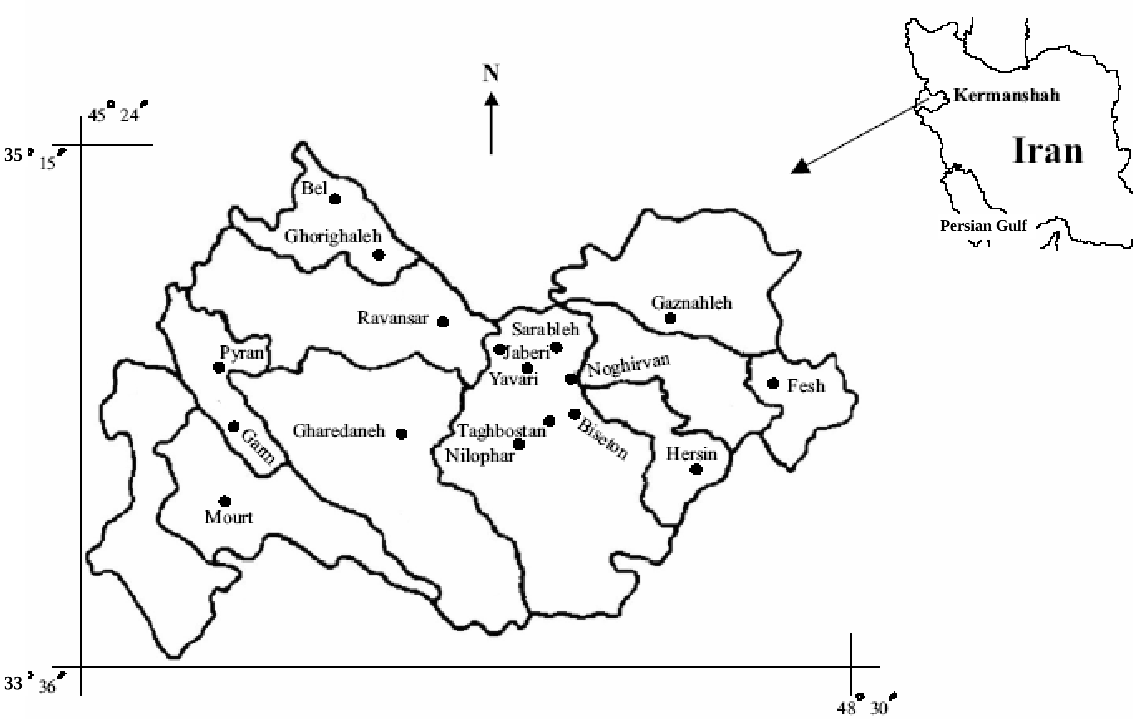

Fig. 1. The distribution of the 17 Sarabs surveyed in the Kermanshah province of Iran

Table 1. The location, area and altitude of the Sarabs included in the survey

Sarab	District	Area of sarab (m^2)	Altitude (m)	Latitude	Longitude
Bel	Paveh	50	800	35° 11′	46° 23′
Biseton	Kermanshah	3000	1284	34° 25′	47° 27′
Fesh	Kangavar	400	1645	34° 36′	47° 58′
Garm	Sarepolezahab	20000	622	34° 27′	45° 55′
Gaznahleh	Songhor	200	1680	34° 45′	47° 34′
Gharedaneh	Javanrood	10000	1400	34° 31′	46° 36′
Ghorighaleh	Paveh	50	1697	34° 54′	46° 34′
Hersin	Hersin	500	1400	34° 16′	47° 47′
Jaberi	Kermanshah	15000	1360	34° 41′	46° 41′
Mourt	Gilangarb	30000	800	34° 14′	45° 58′
Nilophar	Kermanshah	5000	1328	34° 26′	46° 44′
Noghirvan	Kermanshah	5000	1307	34° 44′	47° 26′
Pyran	Sarepolezahab	100	900	34° 29′	45° 57′
Ravansar	Ravansar	10000	1380	34° 43′	46° 39′
Sarableh	Kermanshah	15000	1320	34° 32′	47° 3′
Taghbostan	Kermanshah	300	1312	34° 26′	47° 21′
Yavari	Kermanshah	30000	1306	34° 29′	46° 24′

a) Water quality

The pH, electrical conductivity (EC), dissolved oxygen content (DO), five-day biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) were measured for each Sarab using standard analytical procedures on three to seven occasions during 2001 and 2002 (Table 2). These analyses were carried out by the Department of the Environment, Tehran, Iran.

Table 2. Mean values (± Standard error) for the physico-chemical variables recorded for the Sarabs in 2001 and 2002. The number of samples is shown in brackets. An asterisk denotes detectable limit

Sarab	Substratum nature	COD (mg/l)	BOD_5 (mg/l)	DO (mg/l)	EC (µS/cm)	pH
Bel	Stony; rocky	1* (4)	1* (4)	10 ± 0.4 (4)	400 ± 40 (4)	7.5 ± 0.04 (4)
Biseton	Stony; vegetative	9 ± 0.89 (7)	4.28 ± 0.91 (7)	8.75 ± 0.26 (7)	270 ± 39.7 (7)	7 ± 0.02 (7)
Fesh	Stony; rocky	2.14 ± 0.76 (7)	1* (7)	8.57 ± 0.43 (7)	215 ± 54.1 (7)	7.07 ± 0.03 (7)
Garm	Stony; silty vegetative	14 ± 1 (3)	7.33 ± 0.66 (3)	4.5 ± 0.28 (3)	176 ± 33.3 (3)	7.23 ± 0.08 (3)
Gaznahleh	Stony; silty	1* (3)	1* (3)	8.8 ± 0.23 (4)	306 ± 5.2 (3)	7.56 ± 0.03 (3)
Gharedaneh	Stony; silty; vegetative	31.5 ± 1.25 (4)	18 ± 1.47 (4)	7 ± 0.4 (4)	100 (4)	7.02 ± 0.04 (4)
Ghorighaleh	Stony	1* (4)	1* (4)	8 ± 0.4 (4)	200 (4)	7.6 ± 0.04 (4)
Hersin	Stony	9 ± 0.57 (4)	3.66 ± 1.33 (4)	5.77 ± 0.11 (4)	544 ± 17 (3)	7.1 ± 0.05 (3)
Jaberi	Stony; silty; vegetative	15 ± 1.47 (4)	7.25 ± 0.85 (4)	8 ± 0.4 (4)	100 (4)	7 ± 0.05 (3)
Mourt	Stony; Silty; Vegetative	1* (4)	1* (3)	9 ± 0.2 (4)	600 ± 40.8 (4)	7.27 ± 0.06 (4)
Nilophar	Stony; Silty; vegetative	24.14 ± 6.68 (7)	12 ± 3.4 (7)	7.01 ± 0.43 (7)	497 ± 39 (7)	7 ± 0.21 (7)
Noghirvan	Stony; vegetative	13.14 ± 3.83 (7)	6.14 ± 1.86 (7)	7.27 ± 0.07 (7)	200 (4)	7.21 ± 0.07 (6)
Pyran	Stony	1* (4)	1* (4)	7 ± 0.4 (4)	100 (4)	7.3 ± 0.07 (4)
Ravansar	Stony; silty; vegetative	6.25 ± 1.79 (4)	1.75 ± 0.47 (4)	8 ± 0.4 (4)	100 (4)	7 (4)
Sarableh	Stony; silty; vegetative	36.85 ± 7.65 (7)	19.28 ± 4.20 (7)	6 ± 0.4 (4)	237 ± 17.7 (7)	7 (7)
Taghbostan	Stony; vegetative	28.57 ± 5.9 (7)	15.71 ± 3.48 (7)	7.44 ± 0.27 (7)	179 ± 37.2 (7)	6.95 ± 0.02 (7)
Yavari	Stony; Silty; vegetative	29.14 ± 7.56 (7)	14.28 ± 4.39 (7)	7.74 ± 0.17 (7)	327 ± 25.5 (7)	7 ± 0.37 (7)

b) Benthic macroinvertebrates

Three replicate sample units, each 217.5cm^2, were collected in June 2003 from the substratum of each Sarab by means of an Ekman grab; Gaufin, Harris and Walter [4] concluded from their study that three samples were sufficient to collect at least 50% of the macroinvertebrate species present. Each sample unit was transferred to a plastic container and preserved immediately with formaldehyde solution. Later, the sample units were washed through a 600μm mesh sieve and the retained macroinvertebrates were spread over a large tray for sorting. Animals that were seen easily were picked out and then smaller animals were removed aided by the use of a low power microscope. All animals were transferred to vials containing 70% ethanol plus glycerol. Individuals were identified as far as possible, usually to genus but occasionally to species, using available keys.

c) Statistical analysis

The physico-chemical data were classified and ordinated to determine which of the variables, amongst those measured, were important in characterizing the Sarabs.

Cluster analysis [5] was used to group the Sarabs on the basis of the relative quantitative associations amongst their physico-chemical attributes. We used the average linkage cluster technique which took into account of the average physico-chemical similarity amongst the Sarabs. Sokal and Sneath [5] recommended that the simple unweighted arithmetic average (UPGMA-unweighted pair-group method analysis) should be used when there is no specific reason for choosing an alternative technique. The resulting Sarab associations were then displayed as a dendrogram. Classifying the data in this way imposes discontinuities on what may be continuous data [6]. Consequently, we also applied Principal Component Analysis (PCA), an ordination technique, to the physico-chemical data for comparison.

Faunal similarities amongst the Sarabs were investigated using the same cluster analysis techniques as described above. However, presence-absence data were used [7] rather than quantitative data because they are less affected by sampling error.

Perturbed faunal communities often display reduced diversity, hence this is a frequently recorded descriptor of community structure [8]. In the present study we used taxon richness and the Shannon-Wiener Diversity Index as measures of faunal diversity. The latter measure is based on the relative abundance of the taxa in each sample and is unaffected by sample size [9, 10].

3. RESULTS

a) Water quality

Data obtained during the water quality survey are shown in Table 2. All the Sarabs sampled had a circumneutral pH and, except for Garm, were reasonably well oxygenated. However, conductance differed a great deal from fairly oligotrophic conditions to the ionically richer waters of Mourt and Hersin. Several of the Sarabs had BOD_5 concentrations above naturally occurring values (>7mgO_2/l); [7] which indicates possible organic enrichment. This was particularly true for Sarableh, Gharedaneh, Taghbostan and Yavari. The low COD values show that this enrichment was readily biodegradable, possibly animal or human waste.

Cluster analysis resulted in a dendrogram (Fig. 2) in which the Sarabs were classified into four groups based on their physico-chemical characteristics. Principal component analysis (PCA) showed these groups to be discrete (Fig. 3a) and separated along component 2. This separation appeared to be associated particularly with the dissolved solids concentration (Fig. 3b); Group 4 Sarabs exhibited the lowest conductivities (100μS/cm) recorded during the study (Table 2) and Group 1 Sarabs the highest (averages of 497-600μS/cm). The other physico-chemical variables we measured do not appear to be significant in differentiating the groups of Sarabs from one another.

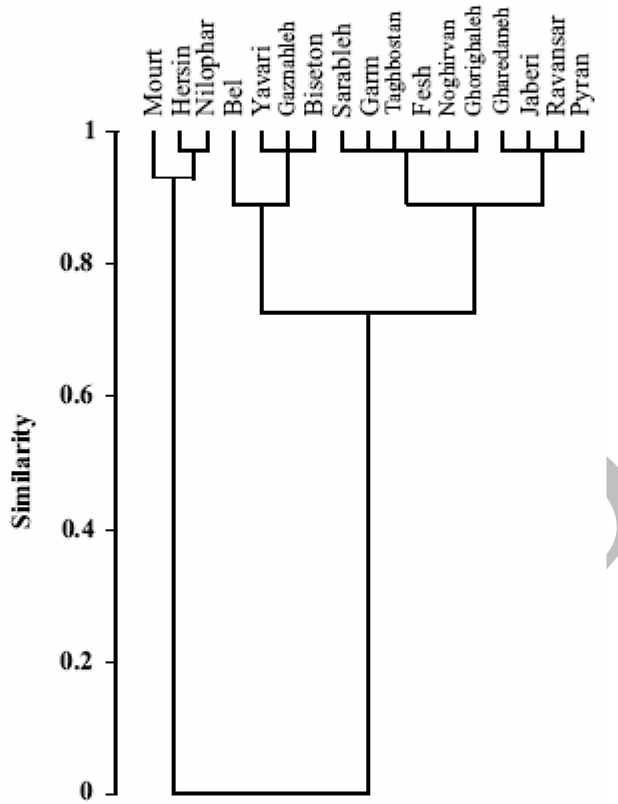

Fig. 2. Classification of 17 of the Sarabs based on their physico-chemical characteristics

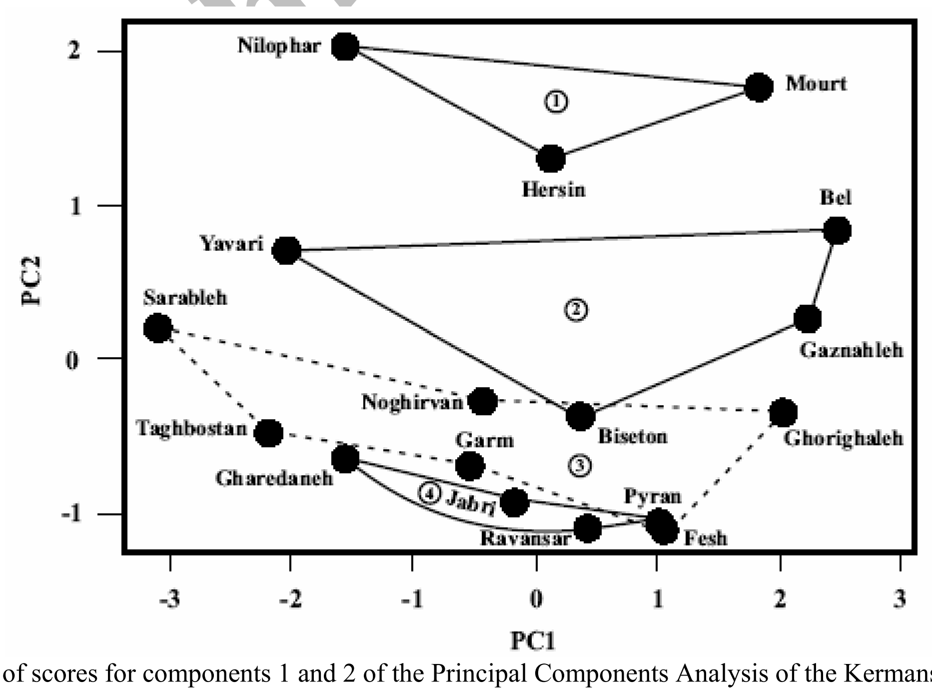

Fig. 3. a) Plot of scores for components 1 and 2 of the Principal Components Analysis of the Kermanshah Sarabs on the physico-chemical data. The polygons are the Sarab groups as defined by Cluster Analysis (Fig. 2)

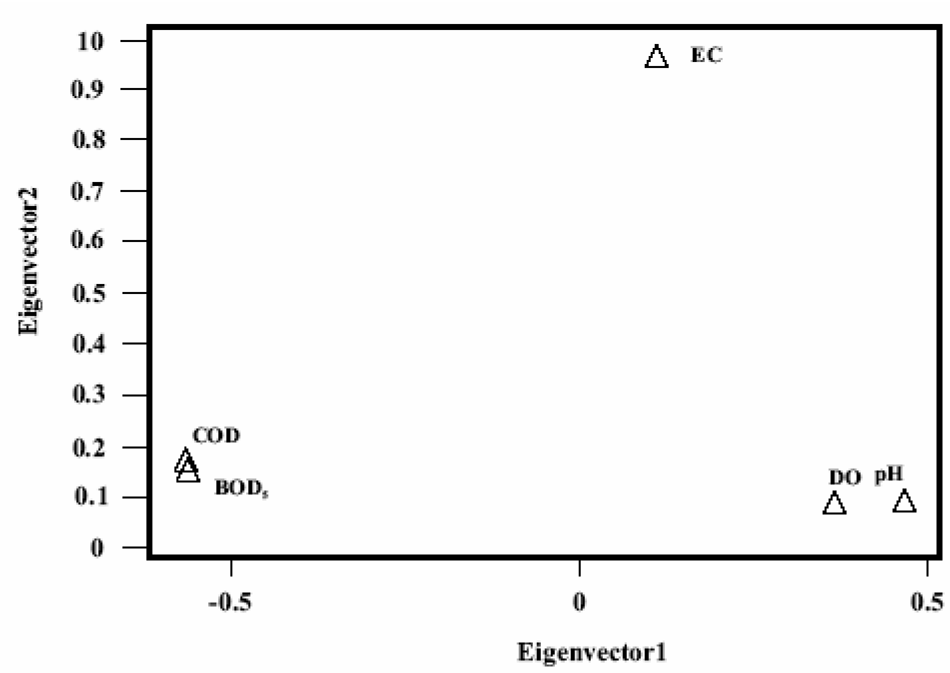

Fig. 3. b) Plot of the eigenvectors for components 1 and 2 of the PCA

b) Macroinvertebrates

The taxa found in the samples from each Sarab in June 2003 are listed in Appendix 1, along with their average abundance and numerical dominance (%) in the faunal community. Taxon richness and diversity values for each Sarab are also provided (Appendix 1).

Fifty-eight taxa were recorded overall. The greatest number of taxa found in any one Sarab was 21 (Yavari) and the smallest was five (Ghorighaleh). The most widespread taxon, found in 94.1% of the Sarabs sampled, was the malacostracan *Gammarus pulex.* Other taxa of widespread occurrence were the chironomid *Tanytarsus sp*. (70.6%), the oligochaete *Tubifex sp*. (64.7%), the gastropod *Viviparus sp.* (58.8%), and the leech *Erpobdella sp.* (58.8%). Except for the last, these taxa were also numerically dominant in several of the Sarabs (Appendix 1). A few taxa were numerically important in at least one Sarab, notably the chironomid *Eukiefferiella sp.*, which accounted for at least 10% of the macroinvertebrate population in four Sarabs. The largest average macroinvertebrate population density was recorded at Ravansar (21531/m^2) and the smallest at Ghorighaleh (2068/m^2).

It is apparent from the dendrogram (Fig. 4) resulting from cluster analysis of the macroinvertebrate data that each of the Sarabs sampled supported a relatively unique combination of taxa. This was particularly true of Hersin, Yavari and Jaberi, each of which had less than 30% of their taxa in common with any of the other Sarabs sampled, but the highest similarity recorded was only 52% (between Noghirvan and Biseton). Seven groups of Sarabs are revealed as components of the dendrogram. These have little in common with the Sarab groupings resulting from the use of the physico-chemical data (Fig. 2).

Of the seven groups of Sarabs identified by cluster analysis of the fauna data (Fig. 4), Group A comprises two Sarabs (Noghirvan and Biseton) which had the highest similarities between their faunas. These Sarabs were of similar size (Table 1) and were located relatively close to each other on the eastern side of the district of Kermanshah (Fig. 1). They were at a similar altitude (Table 1) and had similar water qualities (Fig. 3a) despite being assigned to different Sarab groupings by cluster analysis on the basis of their physico-chemical attributes. There is an indication of organic enrichment (Table 2). Both Sarabs had a stony substratum and supported some aquatic macrophytes. This appears to have provided sufficient structural complexity to promote a relatively high taxon richness (17) and faunal diversity (Av.=0.64). The faunal communities of these Sarabs were dominated by Crustacea (*Gammarus pulex* and *Asellus aquaticus*) and Mollusca (*Viviparus sp*. and *Theodoxus fluviatilis*).

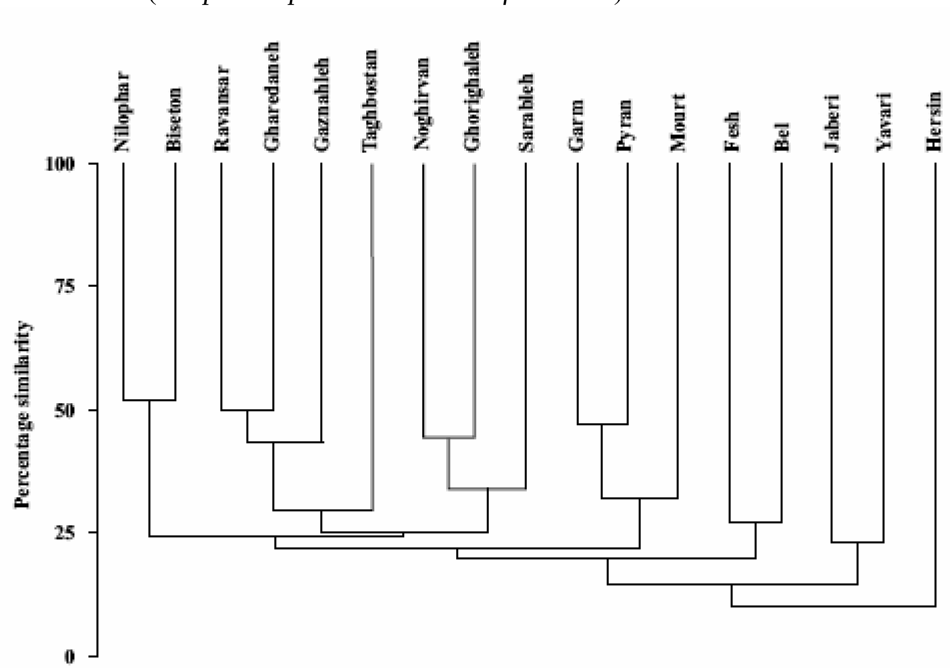

Fig. 4. Dendrogram showing the relationships amongst the Sarabs based on the similarities between their macroinvertebrate faunas

Group B Sarabs comprise Ravansar, Gharedaneh, Gaznahleh and Taghbostan. These were well separated from each other and varied in size from 200/m^2 (Gaznahleh) to 10000/m^2 (Ravansar and Gharedaneh). They were located at a higher altitude (Av.=1443m) than the Group A Sarabs. Chemically, they had a relatively low dissolved solids content (Av.=171µS/cm) and two (Gharedaneh and Taghbostan) were organically enriched. The Group B Sarabs differed from those of Group A in that the substratum, although basically stony with some aquatic macrophytes, was characteristically silty. The faunal population density (Av.=13678/m^2) was much higher than for Group A Sarabs, but taxon richness (Av.=15) and faunal diversity (Av.=0.56) were lower. One feature of the faunal community compared with that of the Group A Sarabs was the relatively greater importance of oligochaetes, such as *Tubifex, Limnodrilus* and *Pristina sp*.A*,* and of the chironomid *Tanytarsus.*

Group C Sarabs comprise Nilophar, Ghorighaleh and Sarableh. These varied more in size (50 to 15000m^2) than the Sarabs comprising groups A and B, but lay at a similar altitude to the Group B Sarabs. Ghorighaleh was, apart from Bel, the smallest Sarab sampled and was located at the highest altitude (1697m). It had a relatively low dissolved solids content (EC=200µS/cm) as Sarableh also had, but this Sarab and Nilophar showed evidence of organic enrichment which was not apparent for Ghorighaleh. Nilophar is used for recreational boating and had a higher dissolved solids content (Table 2). All the Sarabs of Group C had a basically stony substratum, but some siltation was apparent in Nilophar and Sarableh. There were few macrophytes present except in Sarableh. Faunal population density (Av.=5341/m^2), taxon richness (9) and faunal diversity (0.52) were lower for this group than for groups A and B. The faunal community tended to be dominated by *Gammarus pulex* but, unlike the Sarabs of groups A and B, no mollusks were found.

The Sarabs comprising Group D (Fig.4) were Garm, Pyran and Mourt. They were all located at a relatively low altitude (Av.=774m) on the western side of the Province of Kermanshah (Fig. 1). Pyran was small (100m^2), but Garm and Mourt (20000m^2 and 30000m^2 respectively) were, apart from Yavari (Table

1), the largest Sarabs we sampled. Mourt had the highest dissolved solids content (600µS/cm) of all the Sarabs and was used for recreational boating. The other two Sarabs had low dissolved solids contents and Garm seemed to receive slight organic enrichment (Table 2). This last Sarab supported an abundant macrophytic flora, whereas the others contained relatively few plants. The faunal community resembled that of Group C in terms of population density, taxon richness and diversity, but except for the importance of *Gammarus pulex*, it showed a greater similarity to that of Group A in the characteristic importance of the Mollusca. A notable feature is the presence of the ephemeropteran *Caenis* in all Group D Sarabs; it was found in one other Sarab (Yavari).

Group E Sarabs comprised Fesh and Bel (Fig. 4). The former was the most easterly Sarab amongst those we sampled and the latter was the most northerly one. Both were relatively small (Av.=225m^2) but differed considerably in altitude (Table 1). They had low BOD_5 values (1mgO_2/l, detectable limit) and a rocky, stony substratum. Faunal diversity was low (Av.=0.21) reflecting, perhaps, the low structural complexity of these Sarabs owing to the lack of aquatic macrophytes. *Gammarus pulex* was especially dominant (Appendix 1).

The Sarabs of Group F (Fig. 4), Jaberi and Yavari, lay close to each other in the district of Kermanshah (Fig.1). They were large (Av.=22500m^2) and located at a similar altitude (Table 1). Both were organically enriched and had a stony substratum partially covered in silt. Yavari supported an abundance of aquatic macrophytes, whereas Jaberi had fewer plants. Faunal abundance was fairly low (Av.=4268/m^2), but taxon richness (18.5) and faunal diversity (0.58) were similar to Group A. The faunal community was dominated by oligochaetes (especially *Nais communis* and *Tubifex*) and chironomids (particularly *Tanytarsus*).

The final group, Group G, comprised a single Sarab, Hersin, which supported a faunal community that had little in common with those of the other Sarabs we sampled (Fig. 4). This was a relatively small Sarab (500m^2), located in the south of the Province of Kermanshah (Fig. 1). It is used for recreation such as boating and had a stony substratum with few aquatic macrophytes. Both faunal abundance and diversity were low (Appendix 1). The faunal community was dominated by the gastropod *Viviparus* with the eliminthid coleopterans *Limnius* and *Elmis* present as sub-dominants.

4. DISCUSSION

Our study of Iranian Sarabs showed each to support a relatively distinct macroinvertebrate community. The most similar faunas, at the generic level, those of Noghirvan and Biseton, only had a 52% similarity amongst their taxa. The reason for this is unclear. Previous studies on limnocrenes reviewed, for example, by Hynes, Ward and Williams and Feltmate have shown them to be a distinct biotope directly influenced by the nature of the groundwater discharge. They provide uniform conditions, especially with respect to flow, temperature, chemical composition and substratum stability in regions that may otherwise be subject to large seasonal changes. However, it is apparent from the present survey that although each Sarab may provide a relatively uniform environment, they differed considerably amongst each other in terms of water quality (Table 2). The question is: Were these differences crucial in shaping the different faunal communities we found in the Sarabs? When the Sarabs were classified on the basis of quantitative similarities amongst the water quality variables we measured (Fig. 2) and the results compared with those obtained when they were classified on the basis of similarities amongst their macroinvertebrate faunas (Fig. 4), the Sarab groupings were very different. This implies that the water quality variables measured in the present study had relatively little influence on faunal community structure in the Sarabs. This is also apparent from comparison of the physico-chemical data amongst Sarabs comprising any one Sarab group.

Although the macroinvertebrate faunas of the Sarabs sampled in the present survey were relatively distinct from one another, a few taxa occurred fairly widely having a frequency of 50% or more (Appendix 1). These were: *Gammarus pulex*, *Tanytarsus, Eukiefferiella, Tubifex, Erpobdella, Viviparus* and *Dugesia*. They were each also a numerically significant component of the fauna in several of the Sarabs (Appendix 1).

Gammarus pulex occurs throughout Europe where it lives in a wide variety of freshwater habitats, including spring pools, although it is usually absent from water that has a pH less than 5.7 [12, 13]. It is omnivorous, but feeds principally on decomposing plant material. Its occurrence in 94% of the Sarabs we sampled indicates that it is well suited to the Sarab environment. In the Group A Sarabs, *G.pulex* co-dominated with another malacostacan, *Asellus aquaticus*, which was not found in the other Sarabs. This latter species is, like *G.pulex*, widespread throughout Europe and lives in a wide variety of freshwater habitats. It is also omnivorous but feeds mainly on decomposing plant material [13]. In lotic waters, *A.aquaticus* is usually scarce in riffles, whereas *G.pulex* is often abundant. However, in the presence of organic pollution, *A.aquaticus* can displace *G.pulex* from riffles; their co-existence can be an indicator of mild organic pollution. It may be significant that mild organic enrichment is a feature of the Group A Sarabs (Table 2).

The annelids *Erpobdella* and *Tubifex* have been found in all kinds of freshwater habitat and are widely distributed throughout the Palaearctic region [14, 15]. *Erpobdella* is a macrophagous carnivore feeding primarily on oligochaetes and insect larvae. These foods were readily available in all the Sarabs sampled in the present survey and, perhaps, for this reason *Erpobdella* was not a characteristic component of the fauna of any particular group of Sarabs. In contrast, *Tubifex* is a tubicolous detritivore, which is well known to benefit from the organic enrichment of its environment [14, 16]. In the present study, it was an important component, along with other oligochaetes, of the fauna of the group F Sarabs, both of which were organically enriched and had a silty substratum. However, it was actually most abundant in Ravansar (group B) where there was no evidence of organic enrichment. Further research is needed to establish why it was so successful in this particular Sarab.

The triclad most often associated with limnocrenes is *Crenobia alpina*, a common species of underground water [17]. This species is a cold stenotherm and is unlikely to tolerate the warmer conditions of an Iranian Sarab. In the present study, its niche seems to be occupied by *Dugesia* which is more characteristic of warmer climates [17]. This genus preys particularly on gastropods; these were found in almost all the Sarabs inhabited by *Dugesia* (Appendix 1).

The most common gastropod we found was *Viviparus*. This genus occurs throughout Europe and into Asia. It is basically a ctenidial ciliary feeder, but seems mainly to ingest benthic deposits [18]. It prefers hard water, weedy habitats [19], but was not noticeably more successful in such habitats in the present study and was not characteristic of any one group of Sarabs.

Insect groups have been reported to be less abundant and less diverse than non-insect groups in limnocrenes, especially where the water is hard [3]. This generally held true for the Sarabs we sampled. However, the chironomids *Eukiefferiella* and *Tanytarsus,* and the ephemeropteran *Baetis rhodani* were numerically important, sometimes dominant members of the faunal community in many of the Sarabs (Appendix 1). Chironomids are usually prominent members of the insect fauna of coldwater spring pools, especially the orthocladiines which tend to be cold-adapted [11]. In the warmer conditions provided by the Sarabs, the more warm-adapted chironomine genus *Tanytarsus* was particularly prominent, although *Eukiefferiella*, an orthocladiine, was almost as successful. Both genera are widespread in the Palaearctic and include species recorded previously from springs. *Tanytarsus* larvae are essentially detritivores and it is apparent from the present study that this genus was most abundant in those Sarabs that had organically enriched sediments. In contrast, *Eukiefferiella* larvae are mainly grazers on surface biofilms and were particularly abundant in Sarabs that supported extensive stands of aquatic macrophytes which provide a large surface area for the development of such biofilms.

The other insect of importance was *B.rhodani*, a common and widespread species of lotic freshwaters throughout Europe. The euryoecious lotic mayfly, *Baetis tricaudatus*, has been recorded from a spring pool in North America [3] and it seems that *B.rhodani* occupies a similar niche in the Iranian Sarabs. Another mayfly, a species of *Caenis*, had a more restricted distribution being characteristic of the group D Sarabs. Members of this genus are especially associated with mud and silt in lotic or lentic waters where they feed on detritus [19]. The substratum of the group D Sarabs was basically stony, but siltation was evident. Yavari, the only other Sarab where *Caenis* was found, had a similar substratum. However, the restricted occurrence of this mayfly in the Sarabs must be due to other factors because other Sarabs appeared to have an equally suitable substratum.

We expected to find a greater array of Coleoptera in the Sarabs and their apparent scarcity (Appendix 1) may be due to our reliance on the Ekman grab; the Coleoptera we did find are members of the Elminthidae, the adults and larvae of which typically reside under stones (or amongst moss) in streams and rivers [20]. Elminthid (=Elmidae) beetles were believed, previously, to be absent from spring pools [11], but in the present study, both *Elmis* and *Limnius* were present in several of the Sarabs although apparently co-existing only in Hersin (group F) where they were particularly important components of the fauna.

It is apparent from the above that none of the most successful and widespread taxa we found in the Sarabs is limited to limnocrenes. They are characteristically generalist animals that have a wide tolerance of environmental conditions, which occupy a broad range of freshwater habitats (euryoecious), and which have a wide geographical distribution (eurytopic).

The present survey showed that, in general, larger Sarabs supported a higher taxon richness than smaller ones (Fig.5). Similar species-richness by area patterns have been observed in other habitats and, in particular, are a well known feature of island biogeography [1]. Analagously, the Sarabs represent aquatic islands in an arid terrestrial sea. There are various theories that attempt to explain why larger islands support more species [1]. Popular amongst these is that larger islands typically contain a higher diversity of habitats [21]. This appears to be true of the larger Sarabs in our survey which typically contained a greater variety of substrata and more macrophytes, so providing greater structural and biological diversity. That such diversity is important is supported by the fact that two of the larger Sarabs, Nilophar and Mourt, had substantially fewer macroinvertebrate taxa than would be predicted from the taxon-richness by the Sarab-area relationship (Fig. 5). Both of these Sarabs had a largely silty substratum with few macrophytes and hence, a relatively low habitat diversity. As these Sarabs are used for recreational boating, it is possible that this human activity is damaging the plants and inducing siltation of the substratum.

The present survey has shown that each Sarab supported a relatively distinct macroinvertebrate community, although a few taxa were components of the faunas of more than half the Sarabs sampled. The physico-chemical variables we measured do not explain the observed distribution of taxa amongst the Sarabs. Other variables (abiotic and biotic) or a combination of variables must shape the faunal communities we found. Therefore, further research will be necessary before an informed management strategy can be developed that will balance human demands on the Sarabs with the need to preserve their biological integrity.

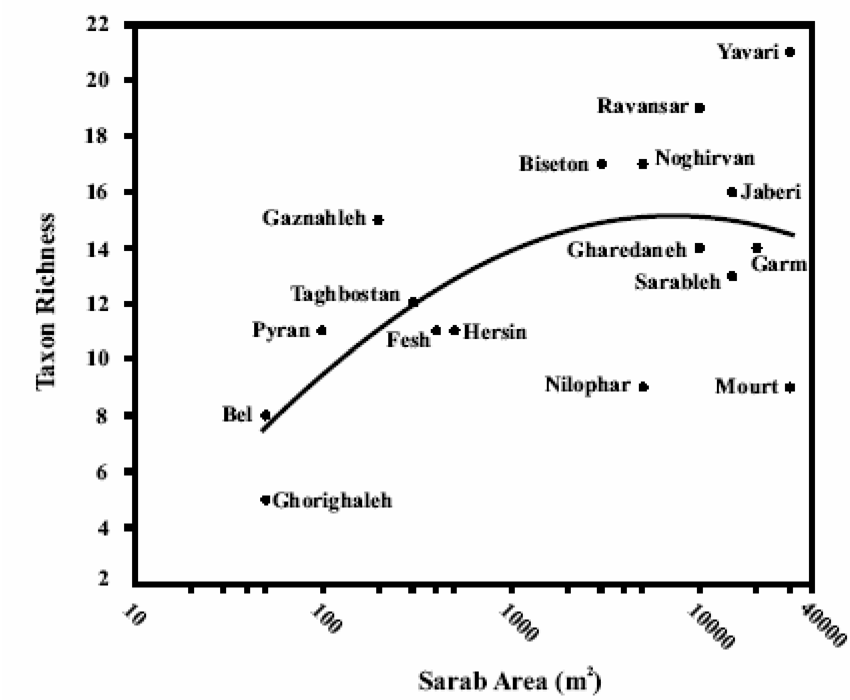

Fig. The relationship between Sarab size and the number of taxa found

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REFERENCES

1. Begon, M., Happer, J. L. & Townsend, C. R. (1990). *Ecology; individuals, populations and communities*. Second Edition. Blackwell Scientific Publications, Oxford, 945.
2. Hynes, H. B. N. (1970). *The ecology of running waters*. Liverpool University Press, 555.
3. Ward, J. V. (1992). *Aquatic insect ecology. 1. Biology and habitat*. John Wiley and Sons, Inc., New York.438pp.
4. Gaufin, A. R., Harris, E. K. & Walter, H. J. (1956). A statistical evaluation of stream bottom sampling data obtained from three standard samplers. *Ecology 37*, 643-648.
5. Sokal, R. R. & Sneath, P. H. A. (1963). *Principals of numerical taxonomy*. W. H. Freeman & Co., San Francisco, 359.
6. Randerson, P. F. (1993). *Ordination*. In J. C. Fry (ed.). *Biological data analysis. A practical approach*. Oxford University Press, 173-217.
7. Hellawell, J. M. (1986). *Biological indicators of freshwater pollution and environmental management*. Elsevier Applied Science Publishers, London, 546.
8. Mason, C. F. (1996). *Biology of freshwater pollution*. Third Edition. Longman, Harlow, England, 356.
9. Edwards, R. W., Hughes, B. D. & Read, M. W. (1975). *Biological survey in the detection and assessment of pollution*. In M.G. Chadwick & G.T. Goodman (eds.). The ecology of resource degradation and renewal. Blackwell Scientific Publication, Oxford: 139-156.
10. Krebs, C. J. (1985). *Ecology*. The experimental analysis of distribution and abundance. Third Edition. Harper and Row, New York, 800.

11. Williams, D. D. & Feltmate, B. W. (1992). *Aquatic insects*. C.A.B. International, Wallingford, Oxfordshire, U.K.358.
12. Fitter, R. & Manuel, R. (1986). *Collins field guide to the freshwater life of Britain and North-West Europe*. W.Collins Sons & Co.Ltd., London, 382.
13. Gledhill, T., Sutcliffe, D. W. & Williams, W. D. (1993). *British freshwater Crustacea: Malacostraca: a key with ecological notes*. Scientific Publication, Freshwater Biological Association. 52, 1-173.
14. Chekanovskaya, O. A. (1962). *Aquatic Oligochaeta of the USSR*. English translation published 1981 by the Amerind Publishing Co.Pvt.Ltd., New Delhi, 513.
15. Sawyer, R. T. (1986). *Leech biology and behaviour. 2. Feeding biology, ecology and systematics*. Clarendon Press, Oxford, 374.
16. Brinkhurst, R. O. (1971). *A guide for the identification of British aquatic Oligochaeta*. Second Edition. Scientific Publication, Freshwater Biological Association, No. 22: 1-55.
17. Reynoldson, T. B. (1967). *A key to the British Species of Freshwater Triclads*. Scientific Publication, Freshwater Biological Association, No. 23.
18. Morton, J. E. (1967). *Molluscs*. Fourth Edition. Hutchinson University Library, London, 244.
19. Janus, H. (1965). *The young specialist looks at molluscs*. Burke Publishing Co.Ltd., London, 180.
20. Elliott, J. M., Humpesch, U. H. & Macan, T. T. (1988). *Larvae of the British Ephemeroptera: A key with ecological notes*. Scientific Publication, Freshwater Biological Association. 49: 1-145.
21. Holland, D. G. (1972). *A key to the larvae, pupae and adults of the British species of Elminthidae*. Scientific Publication, Freshwater Biological Association. 26: 1-58.
22. Usher, M. B. (1986). *Wildlife conservation evaluation*. Chapman & Hall, London, 394.

APPENDIX 1

List of macroinvertebrate taxa and their average abundance (number/m^2), frequency of occurrence (%), taxon richness and average faunal diversity (Shannon-Wiener Index) found in the Sarabs in June 2003. The values shown within brackets are the proportional contributions (%) of numerically important taxa to a Sarab's faunal community.

Appendix 1. List of macroinvertebrate taxa and their average abundance (number/m^2), frequency of occurrence (%), taxon richness and average faunal diversity (Shannon-Wiener Index) found in the Sarabs in June 2003

Taxa	Sarab									Frequency
	Bel	Biseton	Fesh	Garm	Gaznahleh	Gharedaneh	Ghorighaleh	Hersin	Jaberi	
Platyhelminths; Tricladida										
Dugesia sp.	475	475	15	15		46				52.9
Mollusca; Gastropoda										
Assiminiea sp.						1410			31	29.4
Hydrobia sp.				444						5.9
Lymnaea sp.										
Physa sp.										
Succinea sp.									15	5.9
Theodoxus fluvialitis (L.)		828		2697						23.5
Valvata sp.		107						15		23.5
Viviparus sp.		874		372	1318	2943		1548		58.8
Mollusca; Bivalvia										
Pisidium sp.		31			107	46				29.4
Sphaerium sp.										

Appendix 1. (Continued)

Aeolosoma variegatum Veidorsky										
Annelida; Oligochaeta										
Eiseniella tetraedra Savigny			15	31				15		17.6
Haplotaxis sp.	31									
Limnodrilus sp.		751			1824	15				
Lumbriculus sp.		31			31			15		
Nais sp.					77					
Nais communis Piguet										
Nais elinguis Müller	352									
Peloscolex sp.					46			15		
Pristina sp.(A)						6268		138		
Pristina sp.(B)				31		291				
Stylodrilus sp.		215								
Tubifex sp.		766	46	490	1854	61				
Annelida;Hirudinea										
Erpobedella sp.		92	15	15		291			15	58.8
Glossiphonia sp.										
Helobdella sp.		77								11.8
Hemiclepsis sp.									15	5.9
Piscicola sp.										
Arthropoda; Crustacea										
Asellus aquaticus (L.)		1211								11.8
Gammarus pulex (L.)	5364	1976	1946	674	1441	429	1517		322	94.1
Palaemonetes sp.		92								17.6
Psychrodromus sp.					6897	490				29.4
Insect; Ephemeroptera										
Baetis rhodani Pictet				15			460			47.1
Caenis sp.				352						23.5
Ecdyonurus sp.							15			17.6
Insect; Odonata										
Ischnura sp.			15						46	17.6
Insect; Coleoptera										
Elmis sp.	77		15					230		17.6
Limnius sp.		123						322		23.5
Insect; Diptera; Tipulidae										
Dicranota sp.		15								17.6
Tipula sp.			15							5.9
Diptera; Ceratopogonidae										
Ceratopogonidae spp.				46						17.6
Diptera; Culicidae										
Culcus sp.								15		5.9
Diptera; Chironomidae; Tanypodinae										
Ablabesmyia sp.				46						11.8
Chironomidae; Orthocladiinae										
Brillia sp.			31		169					5.9
Chaetocladius sp.									15	11.8
Cricotopus sp.		444			812	169		107		35.3
Eukiefferiella sp.	3801			15	383	77	61			52.9
Halocladius sp.									31	11.8
Paracladius sp.									77	17.6
Paralimnophyes sp.									15	5.9
Paratrichocladius sp.					107					5.9
Rheocricotopus sp.			15							11.8

Appendix 1. (Continued)

Chironomidae; Chironominae										
Chironomus sp.										17.6
Dicrotendipes sp.										17.6
Polypedilum sp.					61			15		23.5
Stempellina sp.									582	5.9
Tanytarsus sp.	15		92		31	2605	15		199	70.6
Abundance	10130	8108	2220	5243	15158	15141	2068	2435	2360	
Taxa richness	8	17	11	14	15	14	5	11	16	
Diversity	0.17	0.71	0.25	0.55	0.57	0.5	0.26	0.4	0.6	

Appendix 1. (Continued)

Taxa	**Sarab**								**Frequency**
	Mourt	**Nilophar**	**Noghirvan**	**Pyran**	**Ravansar**	**Sarableh**	**Taghbostan**	**Yavari**	
Platyhelminths; Tricladida									
Dugesia sp.	398	61			46		31		52.9
Mollusca; Gastropoda									
Assiminiea sp.	61				766			245	29.4
Hydrobia sp.									
Lymnaea sp.								138	5.9
Physa sp.					92			15	11.8
Succinea sp.									
Theodoxus fluvialitis (L.)		828		674					23.5
Valvata sp.		107						15	23.5
Viviparus sp.	1364	874		1747	1241		230		58.8
Mollusca; Bivalvia									
Pisidium sp.		31			674				29.4
Sphaerium sp.								31	5.9
Annelida; Oligochaeta									
Aeolosoma variegatum Veidorsky					15			31	11.8
Eiseniella tetraedra Savigny								92	17.6
Haplotaxis sp.							107		11.8
Limnodrilus sp.		46						31	35.3
Lumbriculus sp.					46		92		29.4
Nais sp.					15	169			17.6
Nais communis Piguet			46					291	17.6
Nais elinguis Müller				15					11.8
Peloscolex sp.									
Pristina sp.(A)			582			46	61		35.3
Pristina sp.(B)				153				582	23.5
Stylodrilus sp.				153					11.8
Tubifex sp.			307	276	10345	276		1395	64.7
Annelida;Hirudinea									
Erpobedella sp.		92		61	690	92	31		58.8
Glossiphonia sp.					15				5.9
Helobdella sp.		77							11.8

Appendix 1. (Continued)

Hemiclepsis sp.									
Piscicola sp.						15			5.9
Arthropoda; Crustacea									
Asellus aquaticus (L.)		1226							11.8
Gammarus pulex (L.)	414	2483	1333	2069	5272	613	812	31	94.1
Palaemonetes sp.	153	92							17.6
Psychrodromus sp.		31			92		61		29.4
Insect; Ephemeroptera									
Baetis rhodani Pictet	15		460	15	659	138	46		47.1
Caenis sp.	230			31				31	23.5
Ecdyonurus sp.								46	17.6
Insect; Odonata									
Ischnura sp.		15							17.6
Insect; Coleoptera									
Elmis sp.		123							17.6
Limnius sp.					15				23.5
Insect; Diptera; Tipulidae									
Dicranota sp.		15					15		17.6
Insect; Ceratopogonidae									
Ceratopogonidae spp.			15					15	17.6
Diptera; Culicidae									
Culcus sp.									
Diptera; Chironomidae; Tanypodinae									
Ablabesmyia sp.								15	11.8
Chironomidae; Orthocladiinae									
Brillia sp.									
Chaetocladius sp.									
Cricotopus sp.					475	536			35.3
Eukiefferiella sp.	15		61		996	8184			52.9
Halocladius sp.						15			11.8
Paracladius sp.									
Paralimnophyes sp.		61						490	5.9
Paratrichocladius sp.									
Rheocricotopus sp.							46		11.8
Chironomidae; Chironominae									
Chironomus sp.				169		690		199	17.6
Dicrotendipes sp.		184			46			123	17.6
Polypedilum sp.						77		199	23.5
Stempellina sp.									
Tanytarsus sp.		15	245		31	56	1349	2161	70.6
Abundance	2834	3064	6177	5363	21531	10907	2881	6176	
Taxa richness	9	9	17	11	19	13	12	21	
Diversity	0.48	0.47	0.57	0.54	0.66	0.83	0.51	0.56	