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Physical, chemical and faunal characteristics of a perennial stream in arid northern Oman

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A study of a 1·5 km stretch of a perennial stream in arid northern Oman describes the physical, chemical and faunal characteristics of riffles, runs and pools. Air temperature seems to influence invertebrate recruitment. Flooding is the most important catastrophic event that alters the physical and chemical environment. Current velocity and substrate composition are also probable factors affecting the community structure. All other chemical conditions except nitrate (–N) were significantly similar in all biotopes. Three vertebrate and 33 invertebrate taxa were recorded. The low faunal diversity is a reflection of a physically controlled system.

Keywords: Arabia; arid zone; fauna; Oman; stream

Introduction

Limnological studies on the seasonal rivers or *wadis* in the Sultanate of Oman are almost non-existent. There are many springs and streams in the mountains of northern Oman and most of these are harnessed by a system of man-made channels, referred to as *aflaj*, for irrigation and other domestic use. Sporadic information is available on the water chemistry of many aflaj and floodwater of *wadis*, but these are mostly based on one or few samples (Stanger, 1986; L. Hutton, pers. comm.). The taxonomy of some freshwater animal groups, such as rotifers, gastropods and fish have been studied (Banister & Clarke, 1977; Brown & Wright, 1980; Wright & Brown, 1980; Brown & Gallagher, 1985; Segers & Dumont, 1993) but very little is known about other freshwater fauna and the microflora. Ecological studies to understand the patterns and processes in the aflaj and *wadis*, including those fed by thermal springs in this arid zone, began in 1990 (R. Victor, unpublished data). The present paper presents the results of a study conducted to evaluate the physical, chemical and faunal characteristics of a perennial stream stretch of a *wadi* in northern Oman.

Study area

Figure 1 shows the study section in the *Wadi* Bani Habib, a major branch of the *Wadi*

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Muaydin at Muaydin village, 9 km north of Birkat Al-Mawz in the foothills of Jebel Akdhar (23°44' N; 57°66' E). This stream flows from north-west to south-east and supplies the Birkat Al-Mawz falaj called Katmain.

The geology of the area is unique because the rocks exposed here represent almost all rock groups found in the Oman mountains. In *Wadi* Muaydin, the oldest rocks belong to the Late Proterozoic and these are exposed under, and with angular unconformity contact, shallow marine limestone and dolomite belonging to the Hajar Super Group (HSG) of Late Permian and Mesozoic age. *Wadi* Bani Habib displays the HSG. Contact between the shallow marine carbonates and the deep oceanic sediments deposited in the Tethys ocean is seen at Tawi Sadh, where syntectonic sediments known as Aruma Group composed of shales, conglomerates and oolitic ironstone is sandwiched between the HSG and the deep oceanic sediments.

In the study area, farming is the major human activity and cultivated plants are date palm, *Phoenix dactylifera* L (Arecaceae), lemon, *Citrus lemon* L (Rutaceae) and alfalfa, *Medicago sativa* L (Fabaceae). Water from the study stream is diverted by a falaj to irrigate the farms. Occasionally, traps are set for fishing and the fish caught are consumed by the locals. Water extraction is another activity near Muaydin village from

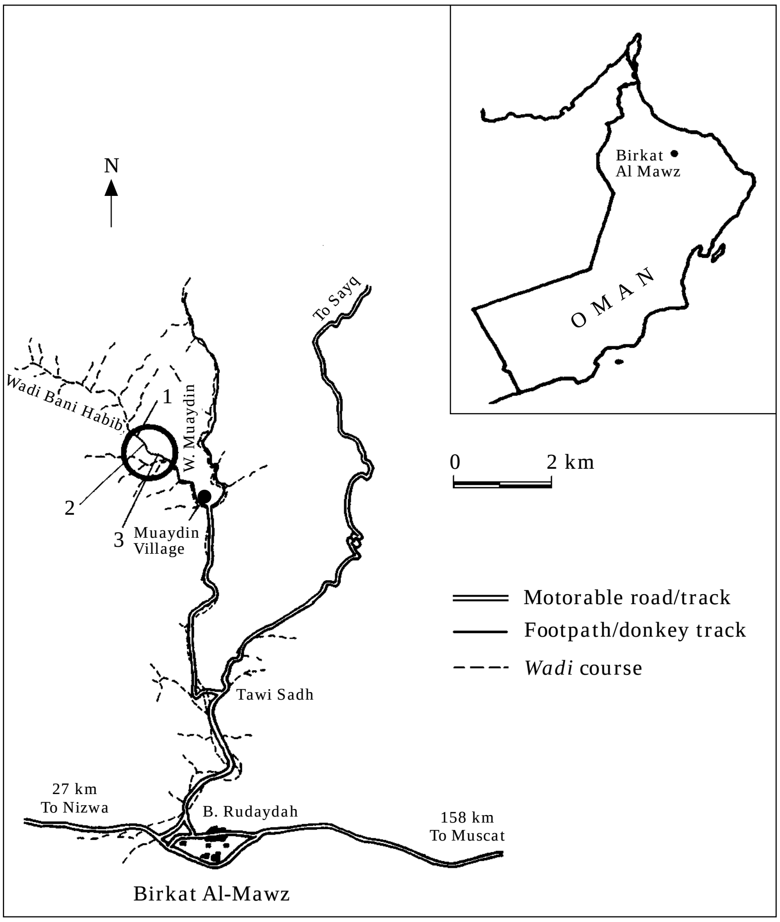

Figure 1. Map of the study area. Circle encloses the study stations on the main channel of *Wadi* Bani Habib branch; inset shows Oman and the location of Birkat Al-Mawz town. Source: Sultanate of Oman topographic maps, Sheets — Birkat Al-Mawz NF 40–7B; Nakhl NP 40–3E.

where tankers transport water for domestic use to other small villages and camps in the area. *Wadi* Muaydin is a scenic recreational spot, but the track leading to the study tributary is not easily accessible by car and is only appealing to the trekker. However, solid refuse associated with human activity is seen at times. Malaria seems to be a problem in this area and the Ministry of Health sprays the ephemeral pools in the *wadi* with temephos (Abate®) for mosquito control. Treatment is weekly when such pools are abundant after the rains, and regulations prevent the spraying of flowing water. When the pools dry up, spraying is terminated.

For this survey, three stations were chosen in a 500 m stretch of the stream. At each station, three biotopes were recognized. These were: (1) an erosional riffle; (2) a depositional pool (a part of the stream continuum; different from the earlier mentioned lentic, ephemeral pools); and (3) a run which is a deep riffle lacking turbulent flow. Station 1 is located about 1·5 km upstream of the Muaydin village and 400 m upstream of a weir regulating flow. Station 2 is 300 m downstream of station 1 and 100 m upstream of the weir. Station 3 is about 1 km upstream of the village and 100 m downstream of the weir.

Methods

Water samples were collected at monthly intervals for a period of 7 months from July 1992 to January 1993. All stations were sampled in the first week of the month between 1000h and 1300h. On each sampling day, two 1 l samples were collected from each of the three biotopes at each station providing a total of 18 samples. The first few samples showed no significant difference in the water chemistry within one biotope of any station ($p > 0{\cdot}05$) and so the two samples taken from the same biotope of each station were subsequently pooled before analysis. Samples were collected in pre-washed polyethylene containers and analysed in the Ministry of Water Resources laboratory for pH, total alkalinity, conductivity, chloride, sulphate, nitrate, calcium, magnesium, sodium, potassium and hardness using the methods recommended by APHA (1992). At the time of sampling, separate water samples were collected in 250 ml glass bottles at each biotope for dissolved oxygen estimation using the iodometric Winkler's method (APHA, 1992). Air-shade and water temperatures were taken in the field using an electronic thermometer (Spring Celsimeter, model super-K). Current velocity was measured using the float method, with a ping-pong ball float filled with stream water (Carlsson, 1967).

Samples of substrata were dug out from each biotope of the three stations to a depth of 10 cm. Loss of some fine sediment while digging caused an inevitable experimental error. Each sample, dried in the sun and in an oven at 100°C for several days to constant weight, was sieved using a set of Endecotts sieves mounted on a sieve shaker (E811 MK3). The mesh sizes used were 16, 8, 2, 0·5 and 0·2 mm. The finest particles passing through the 0·2 mm sieve could not be quantified. Other fractions were approximately categorized to fit the particle size classification given by Jeffries & Mills (1990) and their proportions in the total sample were calculated as percentages. Substrate samples were taken only once, in January 1993.

Just before the first field visit in July 1992, station 3 of the stream had been contaminated with the pesticide temephos (Abate®). This is unusual because temephos treatment is normally restricted to the pools isolated from the lotic stretch. On this occasion, the spray tanks were probably washed at this station. There were many dead leeches and random samples collected contained one or two chironomid larvae only. Temephos has also been known to eliminate midge larvae. Two species of fish, *Garra barrimiae* Fowler & Stenitz 1956 and *Cyprinion micropthalmum* Day 1880, and the toad, *Bufo arabicus* Heyden 1827, were not affected. On 25 August 1992, a flash flood scoured the *wadi* and random samples collected in early September 1992 contained very few chironomid larvae and baetid nymphs. Regular macroinvertebrate samples were collected from October 1992 to January 1992. Only stations 2 and 3 were sampled for macroinvertebrates because of their easy accessibility.

Samples were collected using the kick sampling technique (Hynes, 1970). The substratum was kicked for about 5 min and three samples, one per biotope, were collected at each station. In pool biotopes with low flow, the kicked substrate particles remained as a cloud of suspension for a relatively longer duration and the net was swept through as many times as possible. Any more sampling effort in such a restricted area with poor fauna could have been destructive to the habitat. All benthic samples were fixed in the field using small quantities of 40% formalin. In the laboratory, samples were sieved (mesh size 1·4 mm–250 μm) and the isolated fractions were examined under suitable magnifications (7–40 ×). Invertebrates were sorted and preserved either in 10% formalin or 70% methanol. Fish were collected using a seine net with a stretched mesh width of 1·0 cm. Only a few specimens were preserved in 10% formalin in order to confirm the identification and the rest were released back. Identification of Arabian freshwater fauna is difficult, except for a few groups like fish and molluscs. Therefore, most identifications were made only to supraspecific categories and the number of taxa recorded here refers to distinct morphological units. Identification manuals used were as listed in Ogbeibu & Victor (1989).

All statistical procedures, where appropriate, were adopted from Zar (1984)and the Instat software was used for routine calculations. Harvard Graphics, Windows version 2·0 was used to plot the graph.

Results

Figure 2 shows the fluctuations in the average air and water temperatures measured between 1000 and 1100h for the 7 study months. Water temperature followed the air temperature trend, but the difference between air and water temperatures gradually reduced from hot to cool months, and in December and January the air and water temperatures were almost the same.

Table 1 shows the monthly variations in the average current velocity at the riffle and run biotopes of the three stations. Current velocity at the pool biotopes of all stations was too low to be measured (< 1 cm s^{-1}). Within-station variability of current velocity was not normally distributed and therefore ranked velocity values were analysed using the Mann-Whitney test to compare the riffles and runs. Current velocity was significantly higher in the riffle than in the run of each station during September,

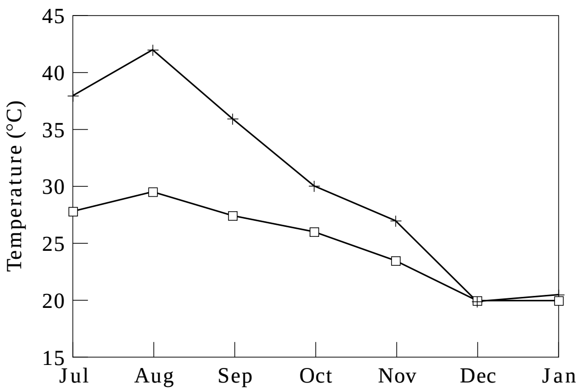

Figure 2. Monthly fluctuations in air (+) and water (□) temperatures at the study stretch, July 1992–January 1993.

Table 1. *Monthly variations in the average current velocity (cm s^{-1}) in riffles and runs, September 1992–January 1993;* N = *3 per biotope per station; values indicated by the same letters were not significantly different (* p > *0·05; Mann-Whitney test)*

Biotope/ station	1992				1993
	September	October	November	December	January
Riffle/1	25	25	25	20	27
Run/1	11	10	9	11	5
Riffle/2	27	25a	50	30	30
Run/2	15	22a	20	11	10
Riffle/3	26	10b	22	7c	30
Run/3	18	10b	8	10c	< 1

November and January ($p < 0{\cdot}05$); current velocities of the riffles and runs of stations 2 and 3 during October and December were not significantly different ($p > 0{\cdot}05$).

With the exception of nitrate (–N) there was no obvious difference in chemical conditions either among biotopes or among stations in any given month. Table 2 summarizes the monthly variations in chemical conditions in the entire study stretch. Comparison of months using ANOVA for all parameters except pH, and Kruskal-Wallis test for pH, showed significant differences ($p < 0{\cdot}05$). Subsequent *a posteriori* multiple comparisons led to the recognition of two general patterns. These were: (i) conditions fluctuating in response to and/or preceding the flood, e.g. pH, total alkalinity, conductivity, sulphate, chloride, magnesium, sodium, magnesium hardness, dissolved oxygen; and (ii) conditions which did not fluctuate much despite flooding, e.g. calcium, potassium, calcium hardness.

Spatial and temporal variations in the nitrate (–N) concentrations of the study stretch were irregular. The ranges recorded in riffles, runs and pools were 0·69–3·96, 0·54–1·64 and 0·50–1·03 mg l^{-1}, respectively. Riffles had more nitrate (–N) than runs and pools. The highest concentrations, 3·96 mg l^{-1} in riffle 1, 2·77 mg l^{-1} in riffle 2 and 1·10 mg l^{-1} in riffle 3 were recorded after the flood.

Table 3 shows the substrate composition of the riffle, run and pool biotopes in the three stations. Riffles 1 and 2 were similar, while riffle 3 was different with a relatively higher proportion of coarse gravel and lesser proportions of small pebbles and medium coarse sand. Runs of all three stations were different from each other. All three pools were similar in the percentage composition of medium and fine gravel, but the proportions of all other components were different.

Thirty-three invertebrate and three vertebrate taxa were collected in the stream during the entire study duration. Table 4 lists the higher taxonomic categories of invertebrates, the number of taxa recognized within each category, their distribution and abundance collected in the three biotopes of the two stations. Although three families of Ephemeroptera were identified, the caenid and leptophlebiid taxa were rare, represented by single specimens and the counts recorded are that of a baetid taxon only. Since the sampling effort used was the same in all biotopes, null hypotheses assuming equality of abundance in all three biotopes of the same station were tested using Chi-square (χ^2) analyses (Table 4); these analyses were subdivided to locate similarities and differences among biotopes. Taxa represented by a combined total of < 50 individuals at each station were not included in these analyses.

Monthly variations in the abundance of the major taxonomic group Chironomidae and the one dominant baetid taxon were monitored. Figure 3 shows the variations in abundance of chironomid larvae at the six biotopes. Except in riffle 2 and pool 3, the

Table 2. *Monthly fluctuations in the chemical parameters of the study stretch; values are mean±S.D. except for pH where the range is given;* N = *9 per month; values identified by the same letters are not significantly different (*$p > 0{\cdot}05$*; ANOVA or Kruskal-Wallis test; Tukey or non-parametric* a posteriori *comparisons)*

Parameter	1992						1993
	July	August	September	October	November	December	January
pH	8·2–8·3a	8·2–8·3a	8·6–8·8b	8·2–8·5a	8·2–8·4a	8·3–8·5a	8·3–8·6a
Total alkalinity (mg $CaCo_3$)	162±8a	164±12a	130±1b	179±18a	169±8a	160±1a	160±1a
Conductivity (µS cm^{-1})	520±0a	475±67b	415±12b	530±12a	515±0a	507±31a	505±11a
Chloride (mg l^{-1})	26±1a	16±1b	17±1b	24±2a	22±1a	23±1a	24±1a
Sulphate (mg l^{-1})	60±4a	59±8a	51±2b	65±5a	69±5a	61±3a	58±5a
Calcium (mg l^{-1})	40±6a	45±3a	43±3a	41±7a	44±16a	42±3a	41±4a
Magnesium (mg l^{-1})	29±2a	22±0b	23±0b	32±2a	31±3a	31±2a	30±3a
Sodium (mg l^{-1})	18±1a	14±1b	11±2b	17±1a	16±0a	18±1a	18±5a
Potassium (mg l^{-1})	1·2±0·1a	1·3±0·1a	1·3±0a	1·2±0·3a	1·3±0a	1·2±0·1a	1·1±0·2a
Calcium hardness (mg l^{-1})	100±16a	110±7a	109±8a	101±22a	111±42a	102±13a	101±15a
Magnesium hardness (mg l^{-1})	121±0a	91±0b	92±1b	129±8a	130±12a	127±12a	127±12a
Dissolved oxygen (mg l^{-1})	4·7±0·4a	5·5±0·4b	4·3±0·3a	5·3±0·8b	5·6±0·5b	6·2±1·1c	5·3±0·6b

Table 3. *Substrate composition of the study biotopes (by percentage) at* Wadi *Muaydin, January 1993*

Biotope	Small pebble >16·0 mm	Coarse gravel 8·0–16·0 mm	Medium and fine gravel 2·0–8·0 mm	Very coarse sand 0·5–2·0 mm	Medium coarse sand >0·2–0·5 mm
Riffle 1	48·6	17·0	21·7	11·6	1·1
Riffle 2	50·7	14·7	24·2	8·0	2·4
Riffle 3	35·1	32·2	25·4	6·9	0·4
Run 1	18·0	22·1	35·0	21·4	3·5
Run 2	37·8	33·3	15·4	9·3	4·2
Run 3	18·4	36·1	42·3	2·2	1·0
Pool 1	1·8	5·2	41·3	48·4	3·3
Pool 2	5·3	22·4	40·2	31·8	0·3
Pool 3	14·0	26·5	38·4	19·6	1·5

abundance increased markedly in December. A similar trend with some variations was observed for the baetid taxon (Fig. 4).

The three aquatic vertebrates, the fish *G. barrimiae*, *C. micropthalmum*, and tadpoles of the toad *B. arabicus*, were ubiquitous. Adults of *B. arabicus*, heavily infested with the icthyobdellid leech, were often found in the pools.

Discussion

Data on the climatic conditions of the study area located near Birkat Al-Mawz (Fig. 1) are not available and the nearby meteorological stations are located at Saiq (distance 21 km; altitude 1755 m a.s.l.) and Seeb (distance 126 km; altitude 15 m a.s.l.). A review of mean monthly air temperatures for the period 1979 to 1992 at Saiq, and 1974 to 1992 at Seeb, showed that May to September are 'hot' months, while November to March are 'cool' months; April and October seem to have transitional temperatures. The present study duration from July 1992 to January 1993 included all these temperature characteristics of the region (Fig. 2).

Coefficients of thermal astatism (Kamler, 1965) calculated for the water temperature during this study ranged from 1·45–1·50 indicating stability. The air temperature seems to be an important factor influencing the ecology of this stream. When the air temperature was high during hot months, the abundance of invertebrates in the stream was low. There was an increase in abundance when the air and water temperatures were almost the same in the cool months. The dominant invertebrates in the stream, both by the number of taxa and by abundance, were insect larvae, and air temperature restricting the breeding activity of adults to cooler months could explain this seasonal increase in abundance.

Flooding, the most important natural event, is catastrophic, altering the physical structure of the stream as well as its chemical conditions and it is always associated with high rainfall. The study stream flooded on 25 August following a heavy downpour in the surrounding mountains. Rainfall data for Saiq from 1979 to 1993 showed that the seasonal pattern is highly variable. High rainfall in the area had been recorded in July and August of several years. Maximum total rainfall (61·8 mm) during the present study (July 1992–January 1993) was recorded in August.

Current velocity and substrate play a major role in structuring stream communities (Jeffries & Mills, 1990; Williams & Feltmate, 1992) and both these factors are influenced by the flood event. The results presented here on the substrates and fauna represent postflood conditions. The riffle biotope of station 2 with a higher current velocity than other biotopes supported the highest abundance of one trichopteran taxon. Current velocity has been known to be a critical factor influencing the occurrence and abundance of trichopteran larvae (Williams, 1981). Substrate

Table 4. *Distribution and abundance of macroinvertebrates in the study stretch; numbers indicate abundance; Chi-square test numbers with same letter are not different at 5% level; – indicates absence*

	No. of taxa	Station 2			Station 3		
		Riffle	Run	Pool	Riffle	Run	Pool
Hirundinidea							
Ichthyobdellidae	1	Not estimated					
Arthropoda							
Insecta							
Ephemeroptera							
Baetidae	3	463a	264b	558c	474d	419d	278e
Diptera							
Tipulidae	1	9	1	7	4	18	14
Simulidae	1	7	–	–	3	3	2
Ceratopogonidae	2	11a	57b	18a	109d	148e	83d
Tabanidae	1	18	2	–	12	11	3
Chironomidae	5	178a	225b	265b	219d	268e	272e
Odonata							
Anisoptera	4	42a	10b	2c	6	8	5
Coleoptera							
Eliminthidae	1	29a	12b	22ab	2	5	13
Hemiptera							
Gerridae	1	–	–	6	1	–	–
Naucoridae	1	–	–	6	1	2	–
Pleidae	1	1	–	–	–	1	1
Trichoptera							
Hydropsychidae	1	2	2	2	13	1	–
a. Family Type A	1	124a	3b	3b	7	9	10
b. Family Type B	1	78a	26b	40b	47d	44d	22e
Chelicerata							
Arachnidae							
Acari							
a. Family indet.	1	11	–	1	3	6	7
b. Family indet.	1	8	1	2	1	2	2
Crustacea							
Ostracoda							
Darwinulidae	1	2	–	–	–	–	–
Cyprididae	3	9	2	7	–	22	21
Platyhelminthes							
Turbellaria							
Dugesidae	1	7	–	–	3	1	1
Mollusca							
Gastropoda							
Pulmonata							
Lymnaeidae	1	2	–	1	–	–	–
Total	33	1001a	605b	940a	905d	968d	734e

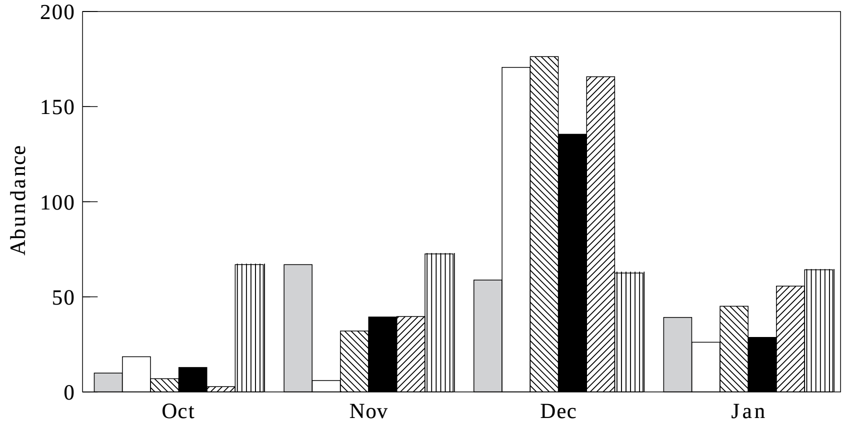

Figure 3. Monthly variations in the abundance of chironomid larvae collected in the six study biotopes, October 1992–January 1993. (▒) = riffle 2; (☐) = run 2; (▧) = pool 2; (■) = riffle 3; (▨) = run 3; (▥) = pool 3.

composition of riffles, runs and pools were different in stations 2 and 3. Substrate, along with current velocity, probably accounts for differences in the abundance of the major groups of invertebrates, Baetidae, Chironomidae and Ceratopogonidae, between these stations as well as among the three biotopes of each station. Monthly variations in the abundance of chironomid larvae and the baetid taxon also reflect the varying colonization potential of the different biotopes.

The water chemistry of running waters is dependent on the physical and geological features of the drainage basin (Bishop, 1973). The chemical parameters estimated here were well within ranges reported for these factors in other waters of the northern Oman mountains (Stanger, 1986). Chemical conditions of streams in the Asir mountains of neighbouring Saudi Arabia were distinctly different (Whitton *et al.*, 1986). Vegetation, land use and other perturbations including pollution are known to cause significant changes in water chemistry.

Application of the pesticide temephos, although restricted to the ephemeral pools of the stream, could still have undesirable effects on non-target organisms. The weekly

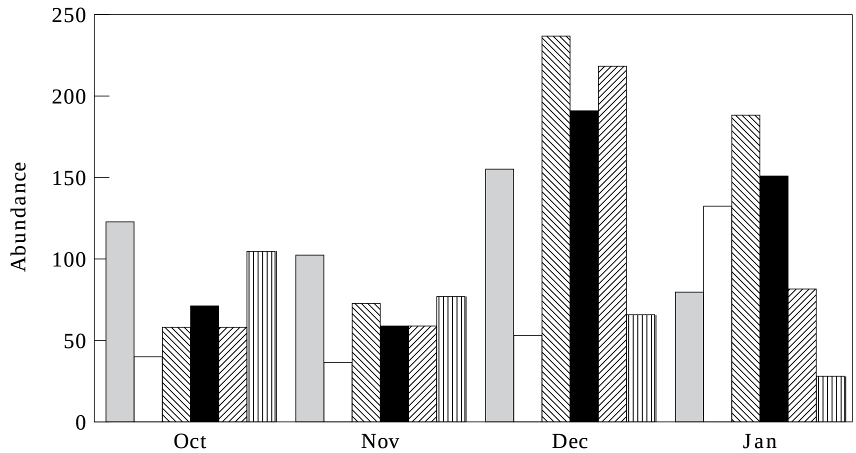

Figure 4. Monthly variations in the abundance of a baetid taxon in the six study biotopes, October 1992–January 1993. (▒) = riffle 2; (☐) = run 2; (▧) = pool 2; (■) = riffle 3; (▨) = run 3; (▥) = pool 3.

treatment of temephos was rigorous during the rainy period; overflow and surface runoff from treated pools are likely to contaminate this stream. The short-term toxicity of temephos to non-target fauna has been demonstrated adequately both in the laboratory and in the field (Dejoux, 1977*a,b*, 1978*a,b*; Dejoux & Elouard, 1977; Elouard & Forge, 1977). Statistical treatment of the surveillance data using correspondence analysis had shown the adverse long-term effects of temephos on the rocky substrate invertebrates and the short-term repercussions on the structure of communities after repeated weekly treatments (Elouard & Jestin, 1982). Observation of temephos-treated pools also suggest that this chemical promotes extensive algal growth because of its high phosphorus content.

Fluctuations in nitrate (–N) seemed to indicate the effects of natural processes like flooding and utilization by the aquatic flora. The highest concentrations of nitrate were recorded in riffles after the floods; massive quantities of goat faecal pellets brought down by the floods alone could be responsible for such increases. The nitrate levels decreased rapidly in runs and pools with benthic algae and the growth of such algae in riffles during low flow also had a similar effect. Differences in the distribution and abundance of invertebrates could not be attributed to any specific chemical parameter because the water chemistry did not differ significantly in all biotopes and stations. Water quality conditions directly affect the structure of stream communities (Bunn & Davies, 1992; Camargo, 1992). The low overall faunal diversity of this stream cannot be attributed to its chemical quality because many tropical streams with similar or poorer chemical qualities have been known to have relatively high diversity (Victor & Ogbeibu, 1985, 1991).

Thirty-three invertebrate taxa recorded in this stream is a low number when compared to other tropical streams. Further taxonomic studies and longer sampling duration may increase the number of taxa to some extent. However, the number recorded is lower than those reported for tropical streams sampled for short periods and also perturbed by urban and agricultural activities (Victor & Ogbeibu, 1985, 1991; Ogbeibu & Victor, 1989). Only the very polluted and/or small streams in the humid tropics have been known to contain similar or less number of taxa (Victor & Dickson, 1985). Diversity tends to be low in physically controlled systems (Odum, 1971). Relatively few species are capable of tolerating the harshness of the environmental conditions associated with the hot and arid climate, thus explaining the poor faunal diversity (Lawrence, 1981; Louw & Seely, 1982; Carl, 1989). The low number of benthic invertebrates recorded here is to be expected. The irregular flood cycles of streams such as this are an added problem for survival.

Baetidae and Chironomidae are common and often the major components of many tropical streams, but the latter are usually the dominant taxa (Victor & Ogbeibu, 1985, 1989; Ogbeibu & Victor, 1989). In the study biotopes, the baetid taxon with a relative abundance of 38–59% was more abundant than chironomids with only 18–37%, while ceratopogonids, seldom abundant in tropical streams, accounted for 11–15%. The heterogenous distribution and abundance of taxa among the different biotopes at the same station is not unusual in temperate and tropical streams. This is a reflection of niche availability governed by physical, chemical and biological factors. All invertebrate taxa recorded in this stream either have terrestrial life stages (e.g. insects, Acari) or have adaptations for surmounting unfavourable conditions such as drought (e.g. ostracods, pulmonates).

Vertebrate diversity in the stream is extremely low. Out of the three species of freshwater fish present in Oman, two were present in this stream. The absence of the ubiquitous cyprinodont *Aphanius dispar* Rüppell was surprising. *Garra barrimiae* is a herbivorous browser on epilithic and benthic algae, while *C. micropthalmum* is a generalist omnivore. Although *B. arabicus* adults are found in pools, they feed on terrestrial invertebrates. The number of *B. arabicus* tadpoles increased in cool months suggesting seasonal breeding activity. Catastrophic floods flushed out the fish, but recolonization was rapid.

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