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Diatoms in Drift – A Preliminary Study in Northern Oman

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ABSTRACT

This first paper on the freshwater diatoms of Oman records 49 species belonging to 17 genera in the stream drift of 13 man-made irrigation channels known as *aflaj*. The number of species in each genus ranged from 1 to 7. Pennales were represented by 16 genera and 47 species while centrales had two species in one genus. The number of species drifting in each *aflaj* ranged from 1 to 15. Only one species occurred in 59% of the localities sampled; two species occurred in 29%; and the occurrence of other species ranged from 6 to 24%. Although all aflaj originated from springs in the northern mountain region with the same underlying geology, there were differences in the surface water chemistry, but the diatom assemblages could not be characterised based on the physical and chemical parameters. All aflaj investigated largely satisfied the standards of drinking and irrigation water quality in Oman. Therefore, the diatom assemblages reported here can be considered as those of clean water. Similarity coefficients based on diatom flora indicated that all aflaj were significantly dissimilar. The need for further studies on the freshwater microflora of Oman is emphasized.

Key Words**:** Diatoms; Drift; Aflaj; Northern Oman; Similarity Coefficient

INTRODUCTION

The downstream transport of organisms by water flow is known as stream drift. Since the downstream displacement of individuals by drift plays an important role in the population biology of stream invertebrates, a large number of investigations have been conducted on this group (Waters 1972, Müller 1974, Kohler 1985, Brittain and Eckland 1988, Gibbin et al. 2010). Studies on the drift of benthic algae are relatively few (Rott et al. 2003), although benthic algae are of extreme importance in stream ecosystems. Diatoms are the most widespread and abundant of all divisions of benthic algae in streams and therefore, form a prominent component in drift. As of now there have been no previous studies on the freshwater diatoms of the Sultanate of Oman.

Despite being arid, Oman has a large number of natural spring-streams (= *Ayun*). Most of these are usually harnessed by humans as *aflaj,* which are man-made and regulated stream channels. Aflaj in general are lifelines providing fresh water for irrigation and other domestic use (Victor 2004). During a study investigating the water quality of 13 aflaj in northern Oman, diatoms were collected in stream drift.

The usefulness of diatoms in assessing the water quality and environmental change has been recognized world-wide (Rolland et al.1997, Potapova and Charles 2007, Beyene et al. 2008). In this preliminary study, the first for Oman and probably the entire Arabian Peninsula, the taxa composition of diatoms found in drift are described with the background information on their physical and chemical environment. These data are also used to assess the similarities of the study aflaj.

STUDY AREA

Figure 1 shows the location of 13 aflaj systems in Oman from where 17 samples were collected. All aflaj were located in the geological province of northern Oman Mountains. The precipitation estimates for northern Oman Mountains are difficult because of the lack of

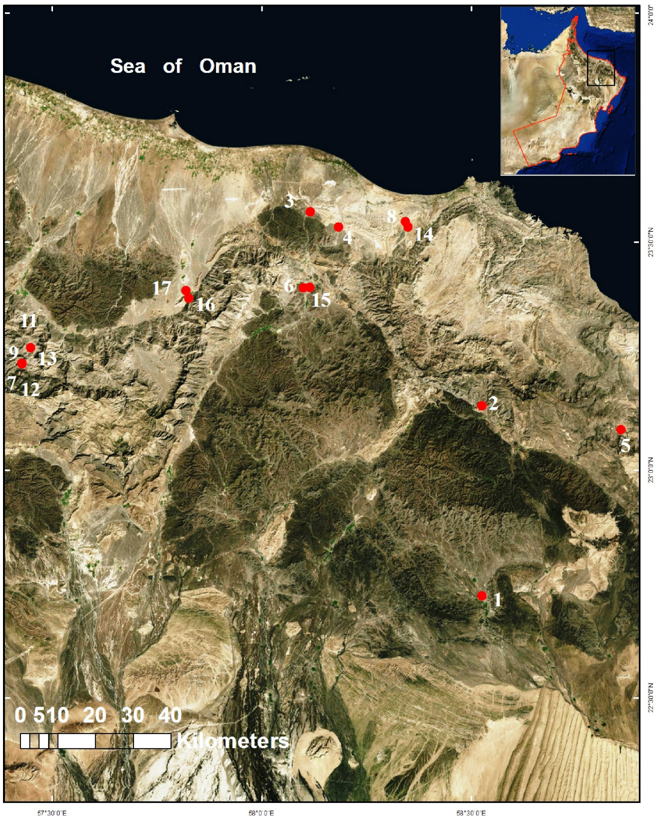

Figure 1. Inset – Map of Oman showing the study area (square) in Al Jabal al Akhdar; Map of the study area showing the locations of the aflaj; locations 10 and 11 are next to each other and indicated by 11 only.

reliable altitude-rainfall relationship (Stanger 1986). Groundwater storage is the greatest in alluvial piedmont surrounding main limestone massifs. Structure of limestone controls the groundwater flow. The Semail nappe mantle sequence, although less productive than carbonates yield bicarbonate waters and hyperalkaline springs are produced by deeply circulating groundwater through low temperature serpentization (Stanger 1986). In the catchments from where the aflaj were sampled, groundwater flow is mostly restricted to alluvial channels often constricted at hard-rock nodal points, thus facilitating interception and recovery by aflaj (Al Lamki and Terken 1996, Victor 2004).

METHODS

Sampling

All samples were collected randomly between January and December, 2006. Water was collected in 5 litre polyethylene bottles for analysis in the laboratory for water quality parameters. Water samples for microflora in drift were collected using 500 ml plastic bottles, a routine method used for collecting nanoplankton and microflora in running waters (Hauer and Lamberti 1996; Eaton et al. 1998) with their mouth facing upstream without disturbing benthic encrustations in the bottom and the side walls of the aflaj. Samples were always taken from undisturbed sections of the aflaj, away from villages and often as close as possible to the source. In each location, 10 replicate samples were taken and filtered through a 5 µm Millipore filter with a hand-held vacuum pump. The filters were preserved with 2–3 drops of 0.1% aniline blue in lactophenol.

Sample Preparation

In the laboratory, the Millipore filters were examined under a binocular microscope (mag. 40-100X) for the presence of diatoms and fungal spores. Filters with diatoms were cut into small pieces and were mounted on metal stubs using double-sided scotch tape and were coated with gold using a low vacuum sputter coater. The specimens were then examined under a Scanning Electron Microscope (JEOL JSM-5600 LV SEM).

Identification

The micrographs were used for the identification of diatom taxa. A simple key of diatoms provided by Needham and Needham (1962) was at first used to recognize diatom genera. The morphology of genera studied showed that there were multiple species under some genera. Since the expertise for the freshwater diatoms was not available, we relied on the generic identifications provided by two phycologists, Dr. Barry Jupp, formerly from Department of Biology, Sultan Qaboos University and Late Prof F.E. Round, Department of Botany, University of Bristol, U.K who studied the material together. They could identify genera, but have to number the species which are considered as distinct morphological entities. In 2007, an interactive identification key for the common diatoms of Britain and Ireland was available as a CD- ROM (EA 2007). For identification of genera this key could be used since all the genera recorded in this study have a worldwide distribution. Species identification provided by this was not considered reliable since it referred to the diatom flora of a restricted geographic region. The revalidation of taxa identification using this key had to be abandoned because it was withdrawn by the publisher, the Environmental Agency of UK, in 2014 stating the data used for this key was old and unreliable. So the list of identifications initially provided by Late Prof. F.E. Round was used for analysis.

Water Quality

Some basic water quality parameters like water temperature, pH, and conductivity were measured in the field. Calcium, magnesium, sodium and potassium concentrations were determined using Inductively Coupled Plasma (ICP) method (Model Perkin-Elmer 3300 DV). Carbonates, bicarbonates, chloride, sulfate and nitrate levels were determined by ion chromatography based on conductivity detection (Model IC25, DINOEX). All methods used were adopted from Eaton et al. (1998).

Similarities of Diatom Communities

Two indices were employed for the evaluation of similarity between pairs of sites sampled. These are (Magurran 2004):

(a) Sorensen's similarity coefficient,
$S_S = 2a / (2a + b + c)$

(b) Marczewski-Steinhaus dissimilarity coefficient,
$C_{MS} = 1 – a / a+b+c$

In both indices,
a = number of species common to both samples
b = number of species unique to the first sample
c = number of species unique to the second sample

RESULTS

In this study covering 13 aflaj in 17 locations, 49 species of diatoms belonging to 13 genera were recorded in the downstream drift. Lack of taxonomic information on the freshwater diatoms in Oman prevented the assignation of species names to the taxa collected. Genera were identified and the species recognized under each genus based on distinct morphological differences was given a species number (e.g. *Navicula* sp.1, *Navicula* sp.2 etc.). Figure 2 presents the scanning electron micrographs of representative genera.

Pennales were represented by 12 genera and 47 species while centrales had two species of *Cyclotella*.

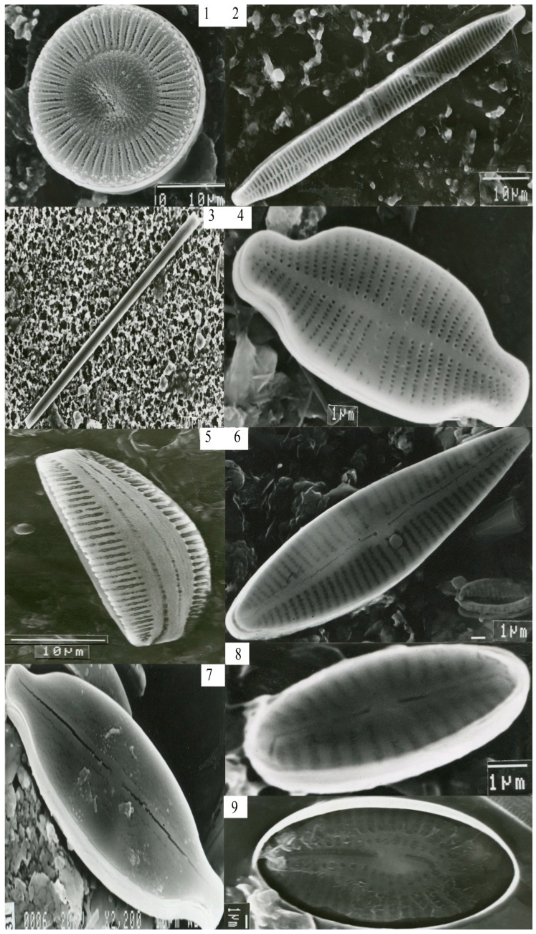

Figure 2a. 1. *Cyclotella*, 2. *Fragilaria*, 3. *Synedra* , 4. *Planothidium*, 5. *Cymbella*, 6. *Gomphonema*, 7. *Placoneis*, 8. *Planothidium*, 9. *Cocconeis*

Among pennales, *Cymbella*, *Nitzchia* and *Navicula* were the most diverse (6-7 species) followed by *Synedra* and *Gomphonema* (4 species each) and *Planothidium* (3 species)

Figure 3 gives the number of species recorded in each of the aflaj. The numbers ranged from 1-15 species. Only one species of *Achnanthidium* occurred in 59% of the localities sampled while *Nitzchia* sp.3 and *Gomphonema* sp.4 occurred in 29%. The occurrence of the other 46 species ranged from 6-24%.

Sorensen's coefficients calculated for evaluating similarities based on diatom flora (Table 1) indicated that all aflaj were significantly dissimilar (≤ 50%). The maximum similarity of 35% was between two sites in Al Ansab (locations 8 and 14). Falaj Al Khuby, Bid Bid and Wadi Bani Awf Exit falaj (locations 6 and 7) had 32% similarity. All other aflaj showed ≤ 30 % similarity.

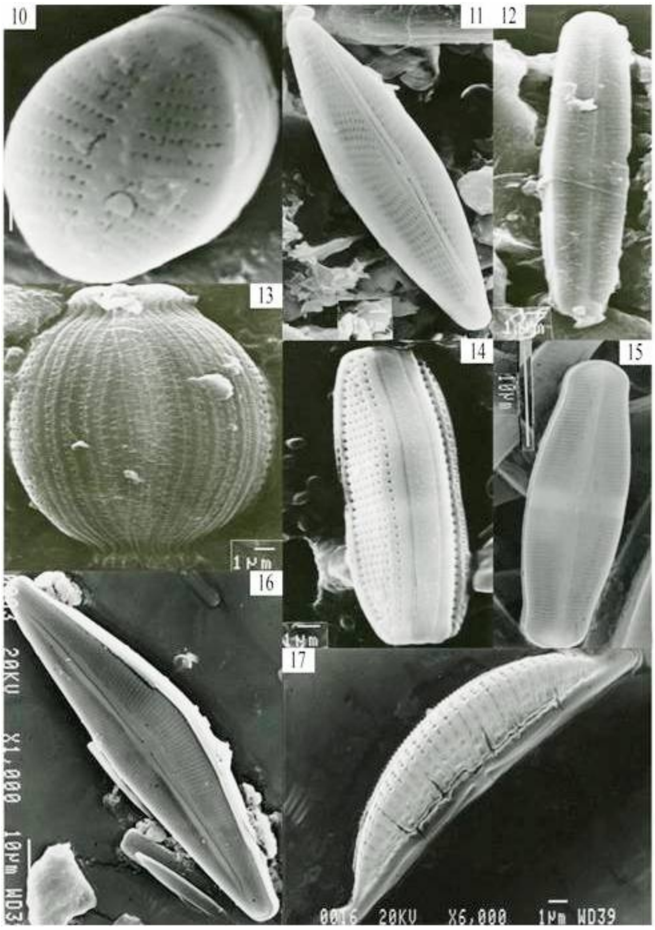

Figure 2b. 10. *Planothidium*, 11. *Navicula*, 12. *Pinnularia*, 13. *Amphora*, 14. *Nitzchia*, 15. *Achnanthidium*, 16. *Cymbella*, 17. *Amphora*

To validate the results in Sorensen's matrix (Table 1), Marczewski-Steinhaus dissimilarity coefficients were calculated. The resulting matrix (Table 2) showed the lowest dissimilarity (79%) between the two sites in Al Ansab, followed by Falaj Al Khuby, Bid Bid and Wadi Bani Awf Exit falaj (locations 6 and 7) with 81% dissimilarity. All other aflaj showed ≥80 % dissimilarity.

The values calculated for both Sorensen's coefficients and Marczewski-Steinhaus dissimilarity coefficients were significantly correlated ($n=134$; $r = 0.71$; $r^2= 0.50$; $P <0.001$).

DISCUSSION

All aflaj sampled for diatoms were in the area of the Hajar mountains in the northern Oman with similar underlying geology. Although there were variations in the chemical parameters of the water (Table 3), there were no significant correlations between these parameters and the number of diatom species collected in this study. The number of samples collected were small (17) and then again only the diatoms found specifically in the drift was collected. Therefore, the number of morphospecies recognized here (49) is likely to be an underestimate. This first study, however provides information on the diatom diversity found in the drift of aflaj in the mountains of northern Oman.

The benthic algae in stream drift have been known to be affected by parameters such as water chemistry, hydrology, and availability of light or substrate (Rott et

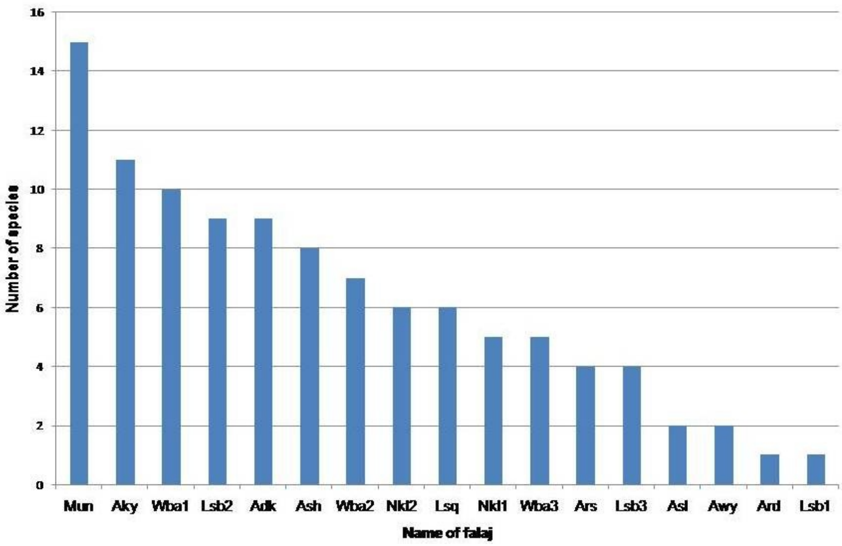

Figure 3. Number of morphospecies drifting in the studied aflaj. Mun = Munjal, Aky = Al Khuby, Wba 1= Wadi Bani Awf 1, Lsb 2 = Al Ansab 2, Adk = Al Dhakaly, Ash = A'Shariq, Wba 2 = Wadi Bani Awf 2, Nkl 2 = Nakhl 2, Lsq = Lisq, Wba 3 = Wadi Bani Awf 3, Ars = A'Rusail, Lsb 3 = Al Ansab 3, Asl = Al Sefalah, Awy = Al Wahebi, Ard = Al Radha, Lsb 1 =Al Ansab 1

Table 1. Physical and chemical (mg L^{-1}) parameters of aflaj water, Al Jabal al Akhdar, January–December 2006

Falaj Name	Water Temp. (ºC)	pH	EC (µS)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3	HCO_3^-	SO_4^{2-}	NO_3^-
Munjal	30	8.9	448	74.1	20.9	20.4	2.1	0.0	112.0	70.0	3.2
Al Khuby	32	9.1	1206	16.5	87.4	109.5	4.1	0.0	447.0	133.0	6.7
W.B Awf 1	27	8.6	436	41.9	25.2	14.9	1.4	0.0	166.2	23.0	5.2
W.B Awf 2	29	9.3	621	44.1	28.1	12.7	2.1	0.0	158.9	19.8	4.3
W.B Awf 3	26	8.3	592	52.2	29.8	16.2	1.8	0.0	236.7	25.6	4.5
Al Ansab 1	28	8.8	1004	67	152	96.7	3.4	0.0	390.5	123.6	5.8
Al Ansab 2	29	8.5	1387	63	155	102.6	3.2	0.0	480.2	141.7	5.1
Al Ansab 3	29	9.0	915	65	142	94.7	2.7	0.0	280.5	112.8	5.2
Al Dhakaly	40	8.1	1250	53.0	84.0	165.0	4.8	0.0	354.0	182.0	1.8
A'Shariq	35	8.7	615	36.7	22.9	45.2	5.7	0.0	134.5	57.0	10.7
Nakhl 1	34	8.4	470	34.0	16.0	36.0	1.8	1.0	110.0	42.4	0.9
Nakhl 2	32	8.4	1064	52.1	63.9	134.9	3.9	16.0	330.2	146.2	4.9
Lisq	30	8.3	838	29.5	68.7	53.3	3.0	0.0	354.0	60.2	7.2
A'Rusail	35	8.4	545	36.1	25.5	110.0	4.1	12.0	218.0	167.0	17.7
Al Sefalah	33	8.4	678	36.4	46.3	63.8	2.3	24.0	239.0	63.0	10.4
Al Wahebi	32	11.5	947	62.3	0.01	184.2	8.7	0.0	0.0	6.1	0.5
Al Radha	33	8.7	1066	34.5	64.7	98.9	5.0	0.0	285.0	97.0	7.2

Table 2. Matrix showing Sorensen's Similarity Coefficients

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0	0	0	0	0.19	0	0.133	0	0	0.222	0	0	0	0.16	0	0	
2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3			0	0	0	0	0	0	0	0	0	0	0	0	0	0	
4				0	0.21	0.125	0.153	0.181	0	0	0.235	0.235	0.2	0.174	0.182	0.166	
5					0.133	0.25	0	0	0	0.166	0	0	0	0	0.222	0	
6						0.322	0.1	0	0	0.244	0.23	0.23	0.117	0.133	0.2	0.19	
7							0.105	0.117	0.153	0.25	0.24	0.173	0.125	0.137	0.21	0.2	
8								0	0	0.117	0.272	0.2	0.35	0.214	0.142	0.133	
9									0	0	0.3	0.125	0	0	0.285	0.153	
10										0	0	0	0	0	0	0	
11											0	0	0	0.08	0.133	0	
12												0.307	0.235	0.077	0.125	0.21	
13													0.133	0.2	0.125	0.21	
14														0.095	0.182	0.166	
15															0.09	0.16	
16																0.266	
17																	

al. 2003). Aflaj are human-made and are maintained by people who not only control the water flow, but also the physical cleanliness of the system, by periodically scrubbing the surfaces and removing the physical and biological encrustations. These activities will also account for the presence of diatoms and other algae in drift. During this study, we took samples from areas devoid of human activity, but the source of benthic algae from where the diatoms originated would have been affected by cleaning activities prior to collection.

All samples were collected during the day time and according to Müller-Haeckel (1971), the drift of diatoms is diurnal since this coincides with photosynthetic activity and cell division.

Table 3. Matrix showing Marczewski- Steinhaus Dissimilarity Coefficients

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1.00	1.00	1.00	1.00	0.90	1.00	0.92	1.00	1.00	0.86	1.00	1.00	1.00	0.91	1.00	1.00	
2		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
3			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
4				1.00	0.88	0.93	0.92	0.90	100	100	0.93	0.87	0.89	0.91	0.90	0.91	
5					0.92	0.86	100	100	100	0.91	100	100	100	100	0.88	100	
6						0.81	0.95	100	100	0.86	0.87	0.87	0.94	0.93	0.89	0.90	
7							0.95	100	0.92	0.86	0.86	0.91	0.93	0.93	0.88	0.94	
8								100	100	0.94	0.84	0.89	0.79	0.88	0.92	0.93	
9									100	100	0.82	0.93	100	100	0.83	0.92	
10										100	100	100	100	100	100	100	
11											100	100	100	0.96	0.93	100	
12												0.82	0.87	0.96	0.93	0.88	
13													0.93	0.89	0.93	0.88	
14														0.95	0.90	0.91	
15															0.95	0.91	
16																0.85	
17																	

Due to their broad distribution and the ability to integrate changes in water quality, diatoms have been widely used in streams as consistent tools for water quality assessment (Feio et al. 2008). Diatoms have also been used for monitoring very heavily impacted systems where other types of organisms are absent (Taylor et al. 2007). Diatom species distributions have also been known to be correlated to salinity (Blinn1993, Gasse et al. 1995). Models using diatoms as biological indicators have been developed in several regions of the world for the integrated measurement of water quality (John 2000, Feio et al. 2007). Diatom indicators also add information to physical and -chemical analysis (Lavoie et al. 2006, 2008).

The result of this study, however do not permit the use of diatom taxa complex in drift as indicators of water quality. All aflaj investigated largely satisfied the standards of drinking and irrigation water quality in Oman which are more stringent than WHO and US-EPA standards. The taxa composition of diatoms reported here can be considered as those of clean water in general and this information may be useful to construct an indicator system after evaluating the diatom assemblages of black and grey wastewater in Oman.

Diatoms in drift are a component of the rheoplankton. The stomach contents of two aflaj fish, the cyprinid *Garra barreimiae* and cyprinodont, *Aphanius dispar* contain diatoms (Victor, unpublished data). *G. barreimiae* is a benthic feeder on algal encrustations while *A. dispar* feeds more in the water column. However, the frequency of diatoms in the diet of these two fish does not indicate that they are important when compared to other food items like micro- and macro-invertebrates (Victor, unpublished data).

The most notable observation of this study is the lack of similarity of the aflaj studied based on taxa composition of diatoms in drift. The two complimentary indices used in this study indicate statistically significant dissimilarities of all aflaj. This was unexpected since the provenance of water in all these aflaj are from the same geological province of the northern Hajar mountains.

Studies on other groups of organisms like zooplankton, macrobenthos and fish in the reservoirs and aflaj of the Hajar Mountain Range show significant similarities (Victor and Victor 2002; Victor, unpublished data). The present results show that similar physical environments support different taxa composition of diatoms assemblages and by extension different biological communities at the first or base trophic level. The man-made nature of the aflaj, the control of flow regimes and maintenance schedules like cleaning frequencies could have also contributed to these dissimilarities, but this phenomenon is worthy of further investigation.

This first study on freshwater diatoms of the Sultanate of Oman would hopefully provide motivation for future studies on this important group of microflora.

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