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Research article

Distribution of non-marine diatoms in surface sediments of streams in Socotra Island, Yemen

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ABSTRACT

Abundance and species composition of non-marine benthic diatom assemblages were studied from surface sediments samples of 11 streams distributed in Socotra Island, located in the northwest Indian Ocean. A total of 145 diatom species, representing 44 genera, were identified. The overall diatom communities appear to be the first recorded off the island. Pennales and non-planktonic taxa were most dominant over centrales and planktonic forms, both in diversity of genera and species. The majority of recognized diatoms are of cosmopolitan distribution. The predominant diatom flora in the surface sediment samples follow: *Synedra ulna, Synedra longissima, Encyonema caespitosum, Encyonema silesiacum, Encyonemopsis microcephala, Mastogloia braunii, Mastogloia dansei, Mastogloia elliptica, Navicula cryptocephala, Navicula cryptotenella, Navicula rhynchocephala, Navicula cincta, Nitzschia amphibian, Nitzschia frustulum, Nitzschia perminuta, Cocconeis placentula, Pleurosira laevis and Staurosirella pinnata*. These are found in addition to the common occurrence of *Amphora coffeaeformis, Amphora Montana, Anomoeoneis sphaerophora, Cyclotella meneghiniana, Cymbella affinis, Diploneis elliptica, Encyonema mesianum, Diploneis smithii, Gomphonema gracile, Gomphonema parvulum, Kobayasia subtilissima, Mastogloia smithii, Navicula minuscule, Navicula notha, Navicula tenelloides, Nitzschia obtuse, Nitzschia palea, Nitzschia scalaris, Synedra nana, Tryblionella acuminate, Tryblionella granulate* and *Tryblionella punctata*. Multivariate statistical techniques including detrended correspondence and cluster analyses were used to summarize changes in the diatom assemblages present in the examined streams. The results indicated six major diatom assemblages with a variation in dominant species. Each assemblage reflects distinctive environmental conditions based on salinity preference of the recognized and dominant.

Keywords: diatoms, multivariate analysis, streams, Socotra, Yemen

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INTRODUCTION

Streams are among the most threatened habitat types in the recent times. Awareness of the deleterious effects of human pressures on streams has resulted in a long history of monitoring using many biological indicators [1–3] A number of studies have evaluated the effects of different stressors on stream assemblages and many assessment systems have been developed including one or more taxonomic groups. Diatoms are the most common and diverse group of algae in many rivers and streams, and thus are important components of these ecosystems [4]. They are considered more suitable for biological monitoring than many other organisms because of their seeming ubiquity, short generation time, sensitivity to changes in nutrient levels, and diverse assemblages [5]. Moreover, diatoms are often used to monitor the environmental changes in rivers and streams because of their range of response to ionic content and composition. Their use in monitoring would be enhanced significantly if species responses to the concentration of major ions in fresh waters were better quantified [6].

In North America, Europe, Australia and Africa, benthic diatoms are frequently used to assess the integrity of stream ecosystems [7–12]. Moreover, several studies have addressed the tolerances and preferences of diatoms along a number of environmental gradients such as salinity, pH, trophy, saprobity and current preference [13–16]. Benthic diatoms are often used for assessing nutrient enrichment [17,16,18,19], salinity [20] and acidity [21–23]. They also give a quick response to environmental changes [24–34]. In addition, they are now increasingly used to examine changes to river systems [35,36].

The present study focuses on distribution of diatoms in some streams from Socotra Island at north-western of Indian Ocean. This island is considered one of the most fascinating places on earth. It has very rich and diverse animals and plants, which are found nowhere else on the earth. Many fauna and flora groups in the island remain to be discovered. Socotra Island has drawn the attention of many researchers in recent times [37–46]. Their studies mainly dealt with the biology, geochemistry, ecology, biodiversity, fisheries and climate of the island. Relatively a few geological studies were carried out on this island due to its extremely isolated location. However, no research on diatom communities from Socotra Island has been carried out. In addition, stream diatom autecology and distribution patterns within the island remain unknown.

The main objective of this study was to obtain preliminary data about the composition of the non-marine benthic diatom flora and their distribution in different eleven streams in Socotra Island. This data can be used as the biodiversity database that will be benefit for monitoring of the environmental change.

ISLAND DESCRIPTION

The Socotra is the largest Yemeni island, located at the northwest Indian Ocean, between the latitudes 12°30'N and the longitudes 54° E. The island covers an area of about 3650 km^2 and it has about 500 km of coastal line and is more than 130 km long from east to west, and 40 km wide from north to south, with a spine of spectacular 1,500 m mountains along its length (Fig. 1). To the north lies Oligocene-Miocene oceanic crust in water depth reaching in excess of 2500m; whilst south of the island depth is generally less than 250m over a distance of 70 km (Laughton, 1966 and Laughton et al. 1970).

The topographic elements in Socotra Island are: (1) The range of Hajar Mountains, which are located at the eastern part of the island along Arida Bay, and extending north east to south west at a distance of about 25 km. (2) The central plateau, which occupies most of the island area. (3) Coastal plains, which are situated in the north and south of the island. (4) The wadis (valleys): The plains are interspersed by many valleys that run in the northern and southern parts of the island. The wadis are represented by small streams. Many of the north-flowing wadis terminate in small fresh or brackish lakes separated from the sea by spits an admixture of fine grey soil. Tectonically, the Socotran Platform was affected by the three phases of extensional tectonics associated with the episodic movement of the Arabian, African and Indian Plates. These are 1: Late Jurassic to Early Cretaceous extension associated with the breakup of eastern Gondwanaland; 2: Late Jurassic to Early Cretaceous extension associated with failed rifting along the Arabian Peninsula Najd Trend (several phases of subsequent structuring, with characteristic translational aspects to the tectonic movement, occurred in the Late Cretaceous/Early Palaeocene and Early Oligocene); and 3: Oligi-Miocene extention related to the rifting of the Gulf of Aden [47].

Climatically, the island lies in the northern tropics (12°30'N– 54°E) of the northwest Indian Ocean and is strongly influenced by the East African–Indian monsoon [37,38,45]. In general, the island is prevailed generally with relatively hot weather of which the average daily temperature in Hajar Mountains ranges between 25– 28 °C. In June and July however, the temperatures reach its extreme and fall during January and February. The average humidity ratio ranges between max 55% in August and min 7% in January. The island is subjected to sharp southern westerly winds during the summer months (June, July, August) with an average speed between 13–18 km/h, whose speed decreases gradually during September till they end at the beginning of October. The average annual rainfall of the island is 150 mm on the coastal plain to upwards of 500 mm in the interior mountains [48], but this quantity fluctuates to a great extent from one year to another.

MATERIALS AND METHODS

Over the course of this study, eleven streams draining into the north and north eastern side of Socotra Island were sampled between 14 and 28 July, 2008 (Fig. 1 and Table 1). The streams are small second or third order systems no more than 4–10m wide and less than 1m deep. They were clear and shallow (max. depth 15–70 cm) (Fig. 2). Stream water specific conductance was generally low (20–250 μS/cm), with higher values potentially representing close to the coast. The stream water pH was alkaline (7.3–8.4) with no clear altitudinal trend.

Diatoms were extracted from 20g of dry sediments of each sample. The sample was first treated by 30% HCl with heating to boiling point in order to remove any carbonate fraction. Each sample was rinsed by distilled water several times to become neutral. The procedure was repeated with H_2O_2 to eliminate the organic matter, and the sample was then rinsed and decanted repeatedly in distilled water. The coarse particles were removed by further decantation. Finally, one drop of the final suspension was dried onto cover slips, then mounted onto slides using Canada Balsam® (R.I = 1.74)

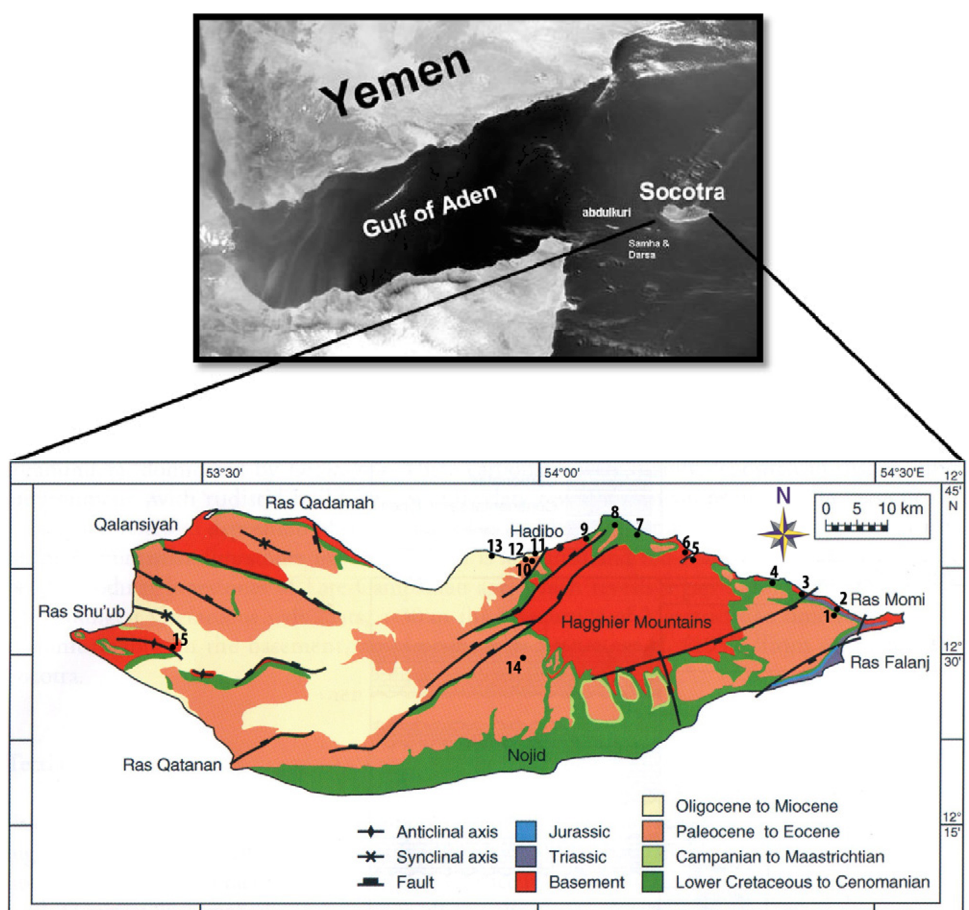

Figure. 1 Map of Socotra Island, showing the location of sampling sites at 11 streams.

for light microscopy investigations. 500 diatom valves were counted and identified in each sample at 1000x magnification with Carl Zeiss microscope.

Nomenclature and identification of diatoms were made using [49–56]. In the case of recently described or redefined taxa, more recent literature was applied [57–67]. All identifications were to species level where possible and the relative abundance values were calculated. The most dominant species that have relative abundance over 5% of the total diatom valves in 15 examined samples were analyzed using the multivariate statistical programs. One barren sample is excluded from the analysis. Examination of community patterns within the dataset was done primarily using detrended correspondence analysis (DCA). Cluster analysis was carried out using Euclidean distance measure and the average clustering method of the investigated sampling sites [68] to distinguish the diatom assemblages.

DIATOM RESULTS

A total of 145 specific and infraspecific diatom taxa representing 44 genera were observed in all examined streams. A list of all taxa encountered is presented in Table 2. All of the recognized diatom flora are reported for the first time for the island. The distribution pattern of the identified diatom communities varies significantly between the studied sites and indicates changes in the floristic composition. At least 45 genera and 142 species of pennate diatoms and at least three genera with five species of centric diatoms were identified. The most dominant diatom flora in the streams were cosmopolitan. The highest and lowest numbers of species were reported at the site 14 (Wadi Serhen) and site 12 (Wadi Hadibo) respectively. The species composition was very variable from stream to other. The dominant species most commonly found in every stream were *Synedra ulna* and *Nitzschia frustulum*. In the Wadi Serhen and Wadi Shafa streams, the diatom flora were most dominant than the others streams, and the species composition was differed considerably.

DIATOM COMPOSITION

While many species were found in the streams from all sites, relative abundances indicate differences in diatom assemblages. In Arer stream at the eastern part of the island, two samples were collected (sites 1 and 2). Low numbers of diatom taxa were recorded with moderately preservation. Site 1 from the downstream region comprised only 10 species, where the strongly dominant species was *Pleurosira laevis*, which has maxima abundance 71% of the total assemblage. The association composed of frequently to sporadic occurrence of *Diploneis bombus*, *Diploneis elliptica*, *Diploneis smithii*, *Eunotia minor, Gomphonema gracile, Hantzschia virgata, Mastogloia dansei*, *Navicula rhynchocephala*, *Stenopterobia delicatissima* and *Synedra ulna*. Site 2 from the mouth of the Arer stream, close to the coast and 19 diatom species were recognized. *Mastogloia braunii* has a maximum abundance, accounted for 44% of the total assemblage, while *Pleurosira laevis* which is abundant at the site 1, it is decreased in its relative abundance to 6.2% to become frequently distributed in site 2. The diatom association is distinguished by common to frequent occurrence of *Mastogloia dansei*, *Mastogloia elliptica*, *Diploneis smithii, Nitzschia amphibia*, *Nitzschia frustulum*,

Table 1. The locations of the studied samples in Socotra Island.

Sample No.	Location	Latitude 'N'	Longitude 'E'
1	Arer stream (fresh water)	12° 33′ 09″	54° 27′ 34″
2	From the mouth of the Arer stream		
3	Terbek area (stream)	12° 34′ 53″	54° 23′ 44″
4	Wadi Shafa	12° 36′ 19″	54° 19′ 18″
5	Wadi Qariat Tawmer	12° 38′ 48″	54° 13′ 19″
6	Wadi Qariat Tawmer	12° 39′ 11″	54° 12′ 36″
7	Wadi Debni	12° 38′ 52″	54° 08′ 32″
8	Wadi Delshieh	12° 41′ 24″	54° 07′ 48″
9	Wadi Souq	12° 40′ 04″	54° 03′ 43″
10	Wadi Serhen	12° 38′ 42″	54° 02′ 11″
11	Wadi Serhen	12° 38′ 44″	54° 02′ 20″
12	Wadi Hadibo	12° 38′ 51″	54° 01′ 39″
13	Wadi Noujahar	12° 38′ 19″	53° 56′ 16″
14	Wadi Serhen (Dexem)	12° 29′ 41″	53° 59′ 29″
15	Dhahadhhah (fresh water)	12° 30′ 40″	53° 27′ 00″

Table 2. List of the identified diatoms in the studied streams sites. (A = abundant, C = common, F = frequent, R = rare, X = excellent, G = good, M = medium, and P = poor)

Diatom flora	Sampling Sites	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Abundance	F	F	F	A	C	F	A	C	A	F	C	R	B	A	A
	Preservation	M	M	P	G	M	M	G	M	G	M	P	M	X	M	G
Achnanthes brevipes intermedia (Kütz.) Cleve.							R									R
Achnanthidium exiguum (Grunow) Czarn.										R		R				
Achnanthidium exilis (Kütz.) Round & Bukht.					R											
Achnanthidium lanceolatum Breb. ex Kütz.						R										
Achnanthidium microcephalum Kütz.																R
Achnanthidium minutissimum (Kütz.) Czarn.																R
Amphora angusta Greg.						R	R								F	R
Amphora coffeaeformis (C.Agardh) Kütz.						F	F						F		R	F
Amphora commutata Grun. in Van Heurck.			R												R	F
Amphora cymbifera Greg.																F
Amphora holsatica.										R					R	F
Amphora montana Krasske.						F		R	R	R					F	F
Amphora normanii Rabenh.										R					R	F
Amphora ovalis (Kütz.) Kütz.															R	
Amphora sp.																F
Amphora veneta Kütz.				F	F											R
Anomoeoneis sphaerophora (Ehrenb.) Pfitz.					R			R	R	R	R	F	R		F	R
Brachysira vitrea (Grun.) R. Ross in Hartley.								R								F
Caloneis budensis (Grunow) Krammer.								R		R						
Campylodiscus bicostatus W. Smith in Roper.											R		F			
Cocconeis disculoides Hust.						R	F									
Cocconeis placentula Ehrenb.						C	F		R		R					
Cocconeis pseudomarginata Greg.						R	R									
Cocconeis scutellum Ehrenb.							R									
Cocconeis speciosa Greg.						R										
Cocconeis sp.						R	R									
Cocconeis thumensis A. Mayer.						R										
Craticula accomoda (Hust) Mann.			R								R					
Craticula ambigua (Ehrenb.) D.G.Mann.											R					
Craticula cuspidata (Kütz.) Mann.											R				R	R
Craticula halophila (Grun. ex Heurck) Mann.																R
Craticula perrotettii Grun.											R					
Ctenophora pulchella (Ralfs ex Kütz.) Williams & Round.					R											

(*continued on next page*)

Table 2 (*continued*)

Diatom flora	Sampling Sites	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Abundance	F	F	F	A	C	F	A	C	A	F	C	R	B	A	A
	Preservation	M	M	P	G	M	M	G	M	G	M	P	M	X	M	G
Cyclotella meneghiniana Kütz.					R				F	R	R	R			R	
Cyclotella ocellata Pant.									R							
Cymbella affinis Kütz.					F				R		F				R	
Cymbella amphicephala Naegeli ex Kütz.					F											
Cymbella ancyli Cleve.																F
Cymbella aspera (Ehrenb.) H. Perag. in Pell.					R											R
Cymbella cistula (Ehrenb.) Kirchner.					R				R							
Dimeregramma fulvum (Greg.) Ralfs in Pritch.						F										
Dimeregramma minor (Greg.) Ralfs in Pritch.						F										
Diplomenora cocconeiformis.						F										
Diploneis bombus (Ehrenb.) Ehrenb. ex Cleve.		R	R			R										
Diploneis elliptica (Kütz.) Cleve.		R			R			R			R					R
Diploneis littoralis (Donk.) Cleve.			R													
Diploneis ovalis (Hilse) Cleve.					R				R		R					
Diploneis smithii (Bréb.) Cleve.		R	F				R	F	R		R	R				C
Encyonema auerswaldii Rabenh.				R											R	
Encyonema caespitosum Kütz.				F	R					C		C			R	
Encyonema gracile Ehrenberg.					F											R
Encyonema mesianum (Cholnoky) Mann.				R	R					F	R	F			R	R
Encyonema minutum (Hilse in Rabenhorst) Mann.				F	R							R			R	
Encyonema silesiacum (Bleisch in Rabenh.) Mann.				C	R			R	R	C	R	R			R	
Encyonemopsis aequalis (W.Sm.) Krammer.				R								R				
Encyonemopsis microcephala (Grunow) Krammer				R	F			F		R	R	R			R	A
Eunotia minor (Kütz) Grunow in Van Heurck.		R	R									R				
Eunotia pectinalis (O.F. Mull.) Rabenh.										R		R				
Geissleria decussis (Østrup) Lange-Bert. & Metzeltin in Lange-Bert.											R				R	
Geissleria paludosa (Hust.) Lange-Bert. & Metzeltin in Lange-Bert.					R			R								
Gomphonema clevei Fricke in A. Schmidt.												R				
Gomphonema gracile Ehrenb.		F	R		F			F	R	C	R	R			R	F
Gomphonema parvulum (Kütz.) Kütz.					R				R						F	R
Gomphonema parvulum exilissimum Grun. in V.Heurck.								R								R

(*continued on next page*)

Table 2 (*continued*)

Diatom flora	Sampling Sites	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Abundance	F	F	F	A	C	F	A	C	A	F	C	R	B	A	A
	Preservation	M	M	P	G	M	M	G	M	G	M	P	M	X	M	G
Gyrosigma acuminatum (Kütz.) Rabenh.					R		R								F	
Gyrosigma diminutum (Grun. in Cleve & Grun.) Cleve.							R						R			
Gyrosigma hippocampus *(* Ehrenb.) Hassall.															R	
Hannaea arcus (Ehrenb.) Patr. in Patr. & Reimer.					R						R					
Hantzschia amphioxys (Ehrenb.) Grun.															R	
Hantzschia virgata (Roper) Grun.									R	R		R				
Hantzschia virgata gracilis Hust.								R				R				
Hippodonta capitata (Ehrenb.) Lange-Bert., Metzeltin & Witkowski.				R	R											
Hippodonta costulata (Grunow) Lange-Bert., Metzeltin & Witkowski.															F	
Hippodonta hungarica (Grunow) Lange-Bert., Metzeltin & Witkowski.					R											
Kobayasia subtilissima (Cleve) Lange-Bert.					C			R	R	R					R	
Lyrella lyra (Ehrenb.) Karayeva						R										
Mastogloia braunii Grun.			A		R			R			R				F	A
Mastogloia dansei (Thwait.) Thwaites & W. Smith.		R	F									R			R	C
Mastogloia elliptica (Ag.) Cleve ex A. Schmidt.			R		R			R	R		R	R			R	A
Mastogloia smithii Thwaites ex W. Smith.			R					R	R			R			R	F
Mastogloia subafrimata.																
Mastogloia sp.			R									R			R	R
Navicula angusta Grun.					R											
Navicula aquaedurae Lange-Bertalot.			R		R											
Navicula arabica Grun. ex A. Schmidt.						R										
Navicula atomus (Kutz.) Grun.					R										R	
Navicula capitoradiata Germain.					R				R							
Navicula cari Ehrenb.									F	R	R					
Navicula cincta (Ehrenb.) Ralfs in Pritch.			R		R				A	R	R				R	R
Navicula clementis Grun.															R	
Navicula cruciculoides Brockm.									R						R	
Navicula cryptocephala Kutz.				R	F		R	R	A		R	R			F	R
Navicula cryptotenella Lange-Bertalot.					R			R	C	C	R	R			R	R
Navicula digito-radiata (Greg.) Ralfs in Pritch.				R	R											
Navicula florinae Moller.															R	

(*continued on next page*)

Table 2 (*continued*)

Diatom flora	Sampling Sites	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Abundance	F	F	F	A	C	F	A	C	A	F	C	R	B	A	A
	Preservation	M	M	P	G	M	M	G	M	G	M	P	M	X	M	G
Navicula globulifera Hustedt.								R	R							
Navicula inflexa (Greg.) Ralfs in Pritch.															R	
Navicula longa (Greg.) Ralfs in Pritch.				R	R										R	
Navicula minuscula Grun. in Van Heurck.						R			R						F	
Navicula notha Wallace.					R			C							R	
Navicula phyllepta Kutz.					R				R						R	
Navicula radiosa Kutz.									R							
Navicula rhynchocephala Kutzing.		R			F	R		R	C	C	F	A			F	
Navicula rostellata Kutz.					R				R			R			R	
Navicula sp.					R				R			R			R	
Navicula tenelloides Hust.				F	F										R	R
Navicula veneta Kutz.									R							R
Nitzschia amphibia Grun.			R	C	C			A	R	F					F	C
Nitzschia fonticola Grun. in Van Heurck.									R							
Nitzschia frustulum (Kütz.) Grun.			R	C	A			A	R	C	F	F			R	F
Nitzschia lanceolata W. Smith.							R								R	
Nitzschia obtusa W. Smith.									R		F		R		R	
Nitzschia palea (Kütz.) W. Smith.									R	R	R	R			R	R
Nitzschia perminuta (Grun.) M. Perag.				F	C			C	R		R					
Nitzschia scalaris (Ehrenb.) W. Smith.					R			R				R			R	R
Nitzschia sigma (Kütz.) W. Smith.													R			
Nitzschia sigmoidea (Nitzsch) W. Smith.											R					
Nitzschia valdecostata.			R	R	F											
Odontella aurita (Lyngb.) Ag.,						R										
Pinnularia gibba (Ehrenb.) Ehrenb.				R	R							R				
Placoneis gastrum (Ehrenb.) Meresch.											R					
Plagiogramma staurophorum (Greg.) Heiberg.							R									
Planothidium delicatulum (Kütz.) Round & Bukht.						F										
Planothidium haukianum (Grun.) Round & Burkht.						F	R									
Pleurosigma angulatum (Quek.) W. Smith.															R	
Pleurosigma strigosum W. Smith.															R	
Pleurosira laevis (Ehrenb.) Compere.		A	R													

(*continued on next page*)

Table 2 (*continued*)

Diatom flora	Sampling Sites	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Abundance	F	F	F	A	C	F	A	C	A	F	C	R	B	A	A
	Preservation	M	M	P	G	M	M	G	M	G	M	P	M	X	M	G
Rhopalodia musculus (Kütz.) O. Müll.															R	
Sellaphora bacillum (Ehrenb.) D.G.Mann.								R								
Sellaphora pupula (Kütz.) Mereschkowsky.												R				
Stauroneis phoenicenteron (Nitzsch) Ehrenb.											R					
Staurosirella pinnata (Ehrenb.) Williams & Round.						A										R
Stenopterobia delicatissima (Lewis) M. Perag.		R														
Synedra acus Kützing.				R	F			R								
Synedra longissima W. Smith.				F	C			R	R		F				C	F
Synedra nana Meister.				F	C			R								
Synedra tabulata (Ag.) Kütz.					F											
Synedra ulna (Nitzsch) Ehrenb.		R	R	A	A		R	F	R	A	C	A	R		A	C
Tropidoneis lepidoptera (Greg.) Cleve.															R	
Tryblionella acuminata W. Smith															A	
Tryblionella apiculata Greg.											R				F	
Tryblionella granulata (Grun.) Mann.							A									
Tryblionella levidensis W. Smith.							R									
Tryblionella punctata W. Smith.							F					R				

Synedra ulna, and sporadic distribution of *Amphora commutate, Diploneis littoralis, Gomphonema gracile, Mastogloia smithii Navicula cincta, Craticula accomoda*, *Diploneis bombus* and *Eunotia minor*.

Terbek stream (site 3) north of the previous sites 1 and 2 at the eastern part of the island. Low numbers of moderately preserved diatom species were recorded and included only 22 taxa. The most dominant species was *Synedra ulna* has a relative abundance 40% of the total community. The association contained the common occurrence of *Encyonema silesiacum* (12%), *Nitzschia frustulum* (19%), *Nitzschia amphibia* (10%), *Nitzschia perminuta* (8%) and *Synedra longissima* in combined with frequently to rare distribution of *Amphora veneta, Encyonema caespitosum, Encyonema mesianum, Encyonema minutum, Encyonemopsis microcephala, Navicula cryptocephala, Navicula tenelloides, Nitzschia valdecostata*, *Pinnularia gibba, Synedra acus*, and *Synedra nana*.

Wadi Shafa stream (site 4) close to the north eastern part of the island. A total of 54 well preserved diatom species were recognized. The most dominant species were *Tryblionella granulate* (36%), *Nitzschia frustulum* (25%) and *Synedra ulna* (22%). The association composed commonly of *Nitzschia amphibia* (11%) and *Synedra nana* in-combined with frequently to sporadic occurrence of many taxa such as *Amphora veneta, Encyonema silesiacum, Encyonemopsis microcephala, Kobayasia subtilissima, Gomphonema gracile, Gomphonema parvulum, Navicula cryptocephala, Navicula cincta, Navicula rhynchocephala*, *Navicula tenelloides* and *Synedra tabulate*.

Wadi Qariat Tawmer stream, two samples were collected (sites 5 and 6), northeast of the island. Site 5 was located in the middle part of wadi Qariat Tawmer, while site 6 was situated close to the island coast, where the stream water was relatively mixed with sea water. Diatom assemblage characteristic site 5 was low diversity and represented only by moderately preserved 22 diatom species. *Staurosirella pinnata* has maximum abundance reaches about 40% of the total assemblage, and associated with common occurrence of *Cocconeis placentula* that accounted for 25%. The association is represented by frequently to rare abundance of *Amphora coffeaeformis, Amphora Montana, Campylodiscus bicostatus, Dimeregramma fulvum, Dimeregramma minor, Diploneis bombus, Geissleria decussis, Lyrella lyra, Navicula arabica, Navicula minuscula*, *Navicula rhynchocephala, Planothidium haukianum, Planothidium delicatulum, Achnanthidium lanceolatum*, and *Odontella aurita*. However, site 6 is also represented by low diatom diversity included moderately preserved 19 diatom species. The predominance taxon was *Tryblionella granulate* which has accounted for 34% of the total assemblage, and associated with common abundance of *Cocconeis placentula* (18%). The diatom association was characterized by frequently abundance of *Achnanthes*

Figure. 2 The studied streams in Socotra Island: (a) Terbek stream, S.3, (b) Wadi Qariat Tawmer close to the sea, S.5, (c) Wadi Qariat Tawmer, S.no.6, (d) Wadi Delshieh, S.8 (e) Wadi Serhen, S.10, (f) Wadi Serhen, S.11, (g) Wadi Hadibo2, S.12, (h) Wadi Noujahar, S.13, (i) Wadi Serhen (Dexem) stream, S.14, (j) Dhahadhhah Stream, S.15.

brevipes var. *intermedia*, *Amphora angusta, Amphora coffeaeformis*, *Cocconeis disculoides, Cocconeis scutellum, Diploneis smithii, Gyrosigma acuminatum, Gyrosigma diminutum, Navicula cryptocephala, Nitzschia lanceolata, Plagiogramma staurophorum, Planothidium haukianum, Synedra ulna* and *Tryblionella punctata*.

Wadi Debni stream (site 7) is a branch of Wadi Delshieh north of Socotra Island. The diatom assemblage encountered from this stream contained only well preserved 31 diatom species. The Debni stream is distinguished from others studied streams by abundance of *Nitzschia* species. *Nitzschia frustulum* was the dominant taxon, has relative frequency of about 47% of the total assemblage, followed by abundance of *Nitzschia amphibia* (30%) and *Nitzschia perminuta* (12%). The diatom association was characterized by frequently distribution of *Navicula notha*, *Kobayasia subtilissima, Encyonemopsis microcephala, Gomphonema gracile, Gomphonema parvulum, Navicula cryptocephala, Navicula cryptotenella, Navicula rhynchocephala*, *Nitzschia scalaris, Amphora Montana, Anomoeoneis sphaerophora, Aneumastus tuscula, Brachysira vitrea, Caloneis budensis, Diploneis elliptica, Diploneis smithii, Hantzschia virgata gracilis, Mastogloia braunii, Mastogloia elliptica*, *Mastogloia smithii, Nitzschia scalaris* and *Synedra acus, Synedra longissima*, *Synedra ulna*.

Wadi Delshieh stream (site 8) is originated from Hafegy mountain and located in the northern part of the island. The studied site is distinguished by diatom assemblage differs from the other streams by predominance of *Navicula* species. The recognized community contained well preserved 39 different diatom taxa. The most dominant was *Navicula cryptocephala*, which is accounted for 49% of the total assemblage and followed by common occurrence of *Navicula cincta* (27%), *Navicula cryptotenella* and *Navicula rhynchocephala*. The association contained frequently to sporadic occurrence of *Anomoeoneis sphaerophora, Cocconeis placentula, Cyclotella meneghiniana, Cyclotella ocellata, Cymbella affinis*, *Cymbella cistula, Diploneis ovalis, Diploneis smithii*, *Encyonema silesiacum*, *Gomphonema gracile, Gomphonema parvulum, Hantzschia virgata, Kobayasia subtilissima, Mastogloia elliptica*, *Mastogloia smithii, Navicula cruciculoides*, *Navicula minuscula, Navicula radiosa, Nitzschia amphibia, Nitzschia fonticola, Nitzschia frustulum, Nitzschia obtusa, Nitzschia palea* and *Synedra ulna*.

Wadi Souq stream (site 9) is located at the north of the island and it originates from Deneqhen mountain. The diatom assemblage is included well preserved 23 diatom species. *Synedra ulna* has a maximum abundance reaches to 35% of the total assemblage. *Encyonema caespitosum* and *Encyonema silesiacum* were recorded commonly (14% and 12.8 respectively) followed by common occurrence of *Navicula cryptotenella, Navicula rhynchocephala, Encyonema mesianum, Gomphonema gracile* and *Nitzschia frustulum*. The diatom association comprised also frequently to rare distribution of *Achnanthidium exiguum, Nitzschia amphibia, Amphora holsatica, Amphora montana, Amphora normanii, Anomoeoneis sphaerophora, Caloneis budensis, Cyclotella meneghiniana, Encyonemopsis microcephala, Hantzschia virgata, Kobayasia subtilissima, Navicula cari, Navicula cincta* and *Nitzschia palea*.

Wadi Serhen stream was originated from Dahzafeq mountain and pour its water into the Arabian Sea at the north. The investigated samples were collected from three sites; 10 and 11 are located at the north of the island, where the wadi was dominant by palm trees. Site 14 was situated in the middle part of the island behind Dexem plateau where the freshwater from the rains made up many lakes with depth of about 4 metres. The diatom flora in the sites 10 and 11 are similar in diversity and abundance and the preservation was well. A total of 35 and 33 diatom species were recognized from these sites respectively. The most dominant diatom species was *Synedra ulna* which accounted for 41% (site 10) to 39% (site 11) of the total assemblage. The diatom association in both sites was relatively similar but differs only in the relative abundance of species. The diatom community was contained frequently to sporadic occurrence of *Anomoeoneis sphaerophora, Cyclotella meneghiniana, Encyonema mesianum, Encyonemopsis microcephala, Gomphonema gracile, Mastogloia elliptica, Navicula cryptocephala, Navicula cryptotenella, Navicula rhynchocephala, Nitzschia frustulum* and *Nitzschia palea*.

The diatom assemblage of site 14 is relatively similar to that recorded in both sites 10 and 11, but differs in the relative abundance of the dominant species with prominent other taxa not recognized in these sites. A total of well preserved 60 diatom species are recorded. *Tryblionella acuminate* is the most dominant taxon and accounted for 28% of the total assemblage. The *Synedra ulna* is less abundant and attains about 22% of the community. The diatom association contained frequently common occurrence of *Amphora angusta*, *Amphora montana*, *Anomoeoneis sphaerophora*, *Gomphonema parvulum, Gyrosigma acuminatum, Hippodonta costulata, Mastogloia braunii, Navicula cryptocephala, Navicula minuscula, Navicula rhynchocephala, Nitzschia amphibia* and *Tryblionella apiculata*. However, the rare abundance diatoms are *Amphora coffeaeformis, Amphora commutate, Amphora normanii, Amphora ovalis, Craticula cuspidate, Cymbella affinis, Encyonema caespitosum*, *Encyonema mesianum, Encyonema minutum, Encyonema silesiacum, Encyonemopsis microcephala, Geissleria decussis, Gomphonema gracile, Gyrosigma hippocampus, Hantzschia amphioxys, Kobayasia subtilissima, Mastogloia dansei, Mastogloia elliptica, Navicula atomus, Navicula cincta, Navicula clementis, Navicula cryptotenella, Navicula notha, Navicula phyllepta, Navicula rostellata, Navicula tenelloides, Nitzschia frustulum, Nitzschia lanceolata, Nitzschia obtuse, Nitzschia palea, Nitzschia scalaris*, *Pleurosigma angulatum, Pleurosigma strigosum* and *Rhopalodia musculus*.

Wadi Hadibo stream (site 12) is originated from Ferdhakhah mountain and the wadi is dominated by palm trees. The stream discharges its water into the Indian Ocean at the north. The diversity of the diatoms is very low and moderately preserved, where the assemblage contained only eight species. *Campylodiscus bicostatus* and *Amphora coffeaeformis* are the most dominant flora and accounted for 36% and 30% of the total community. The association comprised common occurrence of *Synedra ulna* (14%), *Nitzschia sigma* (10%) in-combined with frequently distribution of *Anomoeoneis sphaerophora, Cocconeis placentula, Gyrosigma diminutum* and *Nitzschia obtuse*.

Wadi Noujahar stream (site 13) discharge into the Arabian Sea at the north. The sample is obtained close to the coast where the freshwater mixed with sea water. No diatoms were recorded at this site.

Dhahadhhah stream (site 15) is small, shallow freshwater and originated from granitic mountains that located in the western part of the island. The diatom assemblage is characterised by well-preserved 44 diatom species. *Encyonemopsis microcephala* has maximum abundance accounted for 39% of the total assemblage and followed by *Mastogloia braunii* of about 23%. The diatom association is contained commonly occurrence of *Mastogloia dansei, Mastogloia elliptica, Diploneis smithii, Synedra ulna* in combined frequently distribution of *Amphora commutata, Amphora cymbifera, Brachysira vitrea, Cymbella ancyli, Gomphonema gracile, Mastogloia smithii, Nitzschia amphibia, Nitzschia frustulum, Synedra longissima* and sporadic occurrence of *Achnanthidium microcephalum, Achnanthidium minutissimum, Amphora coffeaeformis*, *Amphora veneta, Anomoeoneis sphaerophora, Craticula cuspidate, Craticula halophila, Cymbella aspera, Diploneis elliptica, Encyonema gracile, Encyonema mesianum, Gomphonema parvulum, Navicula cryptocephala, Navicula cryptotenella, Navicula tenelloides, Navicula veneta, Nitzschia palea* and *Staurosirella pinnata*.

DISCUSSION

Application of multivariate statistical techniques using detrended correspondence and cluster analyses on the most common diatom taxa in the examined 15 sampling sites led to recognition of six different diatom assemblages, with variation in dominant species and composition (Figs. 3–5). The data set includes species that were abundant but present in one and relatively fewer samples, such as *Pleurosira laevis, Staurosirella pinnata, Cocconeis placentula, Encyonemopsis microcephala, Navicula cryptocephala, Synedra ulna, Tryblionella acuminata, Tryblionella granulata*. As well as less abundant species that were nevertheless common, such as *Amphora coffeaeformis, Amphora commutate, Amphora montana, Amphora veneta, Anomoeoneis sphaerophora, Campylodiscus bicostatus, Cocconeis placentula, Dimeregramma fulvum, Dimeregramma minor, Diploneis bombus, Diploneis elliptica, Diploneis smithii, Encyonema caespitosum, Encyonema mesianum, Encyonema silesiacum, Gomphonema gracile, Gomphonema parvulum, Gyrosigma diminutum, Kobayasia subtilissima, Mastogloia braunii, Mastogloia dansei, Mastogloia elliptica, Mastogloia smithii, Navicula cincta, Navicula cryptotenella, Navicula rhynchocephala, Navicula tenelloides, Nitzschia amphibia, Nitzschia frustulum, Nitzschia obtuse, Nitzschia perminuta, Planothidium haukianum, Tryblionella acuminata* and *Tryblionella punctata*.

The results indicate that the distribution pattern of diatoms in the studied sediments streams may influenced by some environmental variables, such as salinity, substrate type and water depth. The recognized diatom assemblages were largely dominated by non-planktonic forms; this attributed to the collection of samples from water depth not exceed than one meter, since the decreasing depth is often correlated with an increased proportion of the benthic and epiphytic habitats.

Assemblage I was recorded only from site 8 at Delshieh stream. This assemblage is characterized by predominance of *Navicula cryptocephala* (49%) and *Navicula cincta* (27%). These two species are considered to be benthic forms, alkaliphilous with pH values 7.5–8.0 and distributed in eutrophic, fresh to slightly brackish water [69,70]. In addition, the diatoms association contains many taxa characteristic of the ecological preferences of fresh to slightly brackish water, such as *Navicula cryptotenella, Navicula rhynchocephala, Cocconeis placentula, Diploneis ovalis, Diploneis smithii, Encyonema silesiacum*, *Gomphonema gracile, Gomphonema parvulum, Hantzschia virgata, Kobayasia subtilissima, Mastogloia elliptica*, *Mastogloia smithii, Navicula cruciculoides*, *Nitzschia amphibia, Nitzschia frustulum, Nitzschia obtusa, Nitzschia palea* and *Synedra ulna*. The diatom

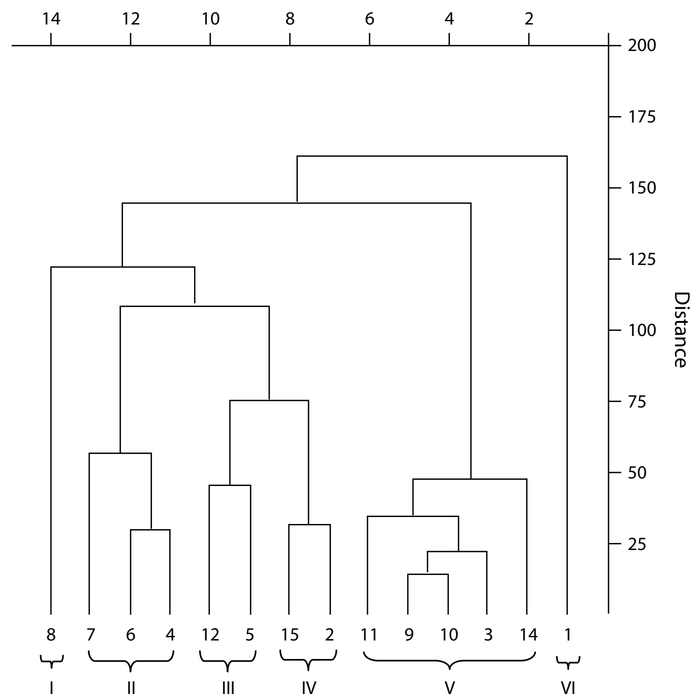

Figure. 3 Cluster analysis of the studied samples based on the relative abundance of the most common diatom taxa.

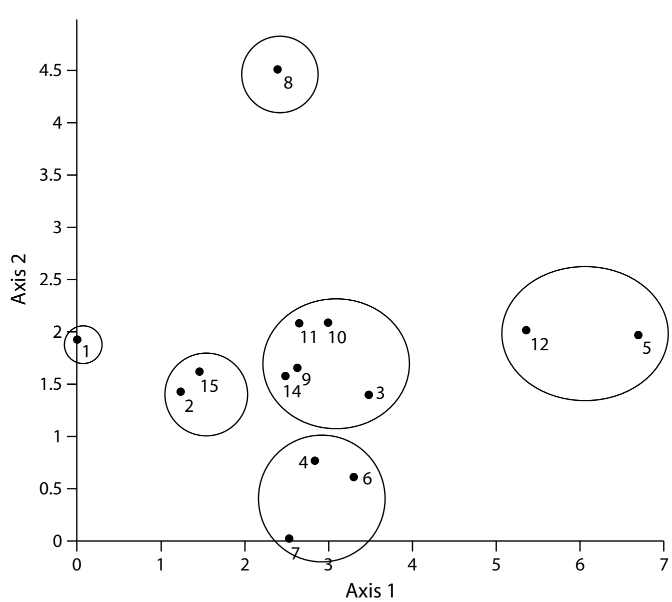

Figure. 4 Detrended correspondence analysis (DCA) differentiated the studied sampling sites into six groups.

assemblage denotes that the Delshieh stream water was freshwater origin with slightly elevated salinity during the arid climatic condition with increasing temperature that lead to some water evaporation.

Assemblage II is characteristic of Wadi Shafa stream (site 4), Wadi Qariat Tawmer stream (site 6) and Wadi Debni stream (site 7). The predominance presence of *Tryblionella granulata* and the frequent occurrence of *Navicula cryptocephala* in the samples of Shafa stream (site 4) and Qariat Tawmer stream (site 6) is resulted from the similarity in environmental conditions in these two sites.

The occurrence of the temperate coastal species *Tryblionella granulata* in site 6 from Wadi Qariat Tawmer reflects high brackish water conditions and the elevated salinity levels in alkaline, eutrophic shallow water. The sample is collected from area where the marine water mixed with freshwater of the stream. This may the reason to abundance of *Tryblionella granulata*. However, in site 4, this species is considered to be of allochthonous origin, and it has been transported into the Shafa stream by marine currents, particularly during the season of higher sea level, since the species is a marine diatom, found in coastal lagoons and estuaries [85], very rare in continental environments [89,80]. Moreover, its occurrence may be due to the ability of tides to transport cells in a diurnal basis, with high spring tides or storm surges being especially proficient at mixing species from different environments [90,91].

On the other hand, the similarity between sites 4 and 7 is represented in the abundance of freshwater flora including, *Nitzschia frustulum* (25% and 47% respectively), and *Nitzschia amphibia* (11% and 30% respectively). *Nitzschia frustulum* is a freshwater, alkaliphilous form, distributed also in meso- to eutrophic, slightly brackish water [71,72] tolerant to pollution and also mesohalobic species [73]. *Nitzschia amphibia* is a benthic, alkalibiontic, with pH value over 8, lives in eutrophic freshwater [69,71]. Beside the dominant taxa many other freshwater forms are recorded infrequently within the assemblage such as *Kobayasia subtilissima, Encyonemopsis microcephala, Gomphonema gracile, Gomphonema parvulum, Navicula cryptocephala, Navicula rhynchocephala*, *Nitzschia scalaris*, and *Synedra ulna*.

Although the cluster and DCA analyses appeared a similarity between the three sites 4, 6 and 7, based on the dominant diatoms, nevertheless each site is characterized by diatom association differs relatively from the other sites. Site 6 is characterized by diatom association contained frequently of *Achnanthes brevipes* var. *intermedia*, *Amphora angusta, Amphora coffeaeformis*, *Cocconeis disculoides, Cocconeis scutellum, Diploneis smithii, Gyrosigma acuminatum, Gyrosigma diminutum, Nitzschia lanceolata, Plagiogramma staurophorum, Planothidium haukianum* and *Tryblionella punctata*. These taxa characteristic brackish water and denote to elevated salinity. This community not recorded in both sites of Wadi Shafa stream (4) and Wadi Debni stream (7). However, site 7 of Wadi Debni stream comprises other diatom association represented by frequently occurrence of mixed slightly brackish to freshwater forms such as *Amphora Montana, Anomoeoneis sphaerophora,*

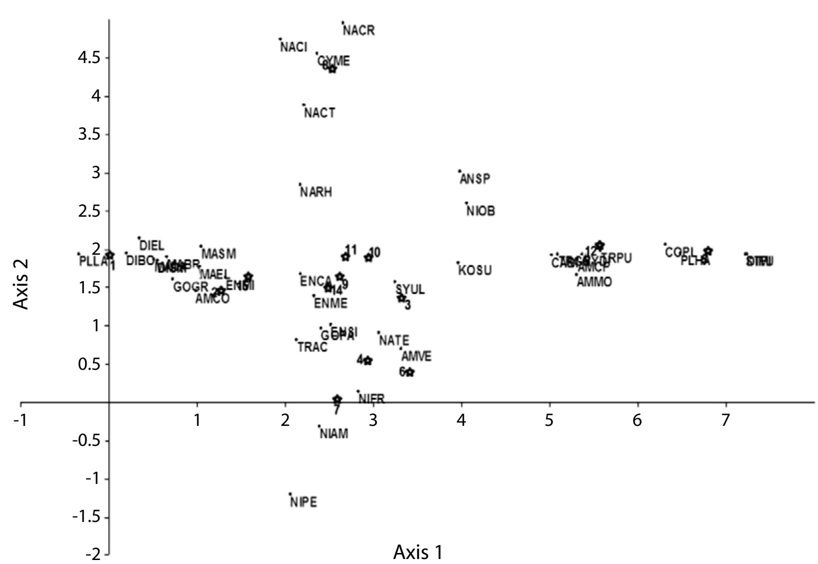

Figure. 5 Detrended correspondence analysis (DCA) based on dominant diatom species.

Aneumastus tuscula, Mastogloia braunii, Mastogloia elliptica and *Navicula notha*. Site 4 of wadi Shafa stream is contained diatom association differs from the previous sites and represented by frequently occurrence of many freshwater forms such as *Amphora veneta, Cymbella affinis, Cymbella aspera, Diploneis elliptica, Encyonema mesianum, Encyonema silesiacum, Navicula cincta, Navicula tenelloides, Pinnularia gibba* and *Synedra nana*. The diatom communities in both sites 4 and 7 elucidate freshwater to slightly brackish water environment.

Assemblage III was recognized from Wadi Qariat Tawmer stream (site 5) and Wadi Hadibo stream (site 12). Although similarities in diatom community composition can be seen between these streams, the order and dominance of species differed between them, with the most obvious examples being the abundance of *Staurosirella pinnata* (39%), associated with common occurrence of *Cocconeis placentula* (22%) in sediment streams of Wadi Qariat Tawmer (site 5) in comparison with sediment stream of Wadi Hadibo (site 12) and the abundance of *Campylodiscus bicostatus* (32%) co-dominant with *Amphora coffeaeformis* (29%) in sediments stream at site 12 in comparison with sediment streams at site 5. Differences in the dominant diatoms between the streams 5 and 12 may be related to a number of environmental factors, such as variations in the substrate type.

However, similarity between these sites (5 and 12) is attributed to a great abundance of epiphytic and benthic pleiroeuryhaline and mesohalobous diatom species with considerable numbers of some coastal marine forms. Of these taxa are *Amphora coffeaeformis*, *Campylodiscus bicostatus, Cocconeis placentula, Dimeregramma fulvum, Dimeregramma minor, Diploneis bombus, Lyrella lyra, Navicula arabica, Navicula* and *Odontella aurita*.

Staurosirella pinnata and *Cocconeis placentula* reached maximum abundance throughout Wadi Qariat Tawmer stream (site 5). *Staurosirella pinnata* is eurytopic form, common in the littoral part of eutrophic waters, epiphytic, beta-mesosaprobic and preference for oligotrophic water with relatively low conductivity, it lives in fresh and brackish water as plankton or epiphytic, alkaliphilous, with pH value 7.5–8.0 [69,74,55,56]. *Cocconeis placentula* is a widespread eurytopic species, epiphytic on aquatic plants and other objects; more commonly found in circumneutral to alkaline waters with pH values 7.5–8.0, and recorded in waters up to 17–20 g/l salinity [75,76,69]. These two species reflects warm, shallow, eutrophic slightly brackish water conditions [77]. They denote the development of macrophytes in quite parts of the eutrophic water [78].

Campylodiscus bicostatus and *Amphora coffeaeformis* have maximum abundance with common appearance of *Synedra ulna* and *Nitzschia sigma* in Wadi Hadibo stream (site 12). *Campylodiscus bicostatus* is a benthic, mesohalobous species [79]. *Amphora coffeaeformis* is a benthic, polyhalobous, pleioeuryhaline [79]. It can lives as epipelic, epiphytic or aerophilous in stagnant or running water of medium to high conductivity, it is eurythermal [70]. *Nitzschia sigma* is an eutrophic mesohalobous species, commonly found in water with pH value 7.5–8.3 [80,81]. Generally, the common occurrence of epiphytic, mesohalobous taxa combined with some coastal marine forms suggests elevated salinity and high brackish water conditions with development of macrophytes characteristic the Wadi Qariat Tawmer stream (site 5) and Wadi Hadibo stream (site 12). As well as high abundance of eutrophic taxa reflects high nutrients matter at these localities.

Assemblage IV was observed in sediments from the mouth of the Arer stream (site 2) and from Dhahadhhah stream (site 15). The good similarity between these sites is due to the predominance of slightly brackish water benthic species combined with many freshwater forms. *Mastogloia braunii* has maximum abundance in the two sites reached 44% and 32% respectively. This species is a benthic form, common in brackish water, estuarine "mesohalobous", alkaliphilous [82–84]. The diatom association of both sites contained also common to frequent occurrence of others mesohalobous forms such as *Mastogloia dansei*, *Mastogloia elliptica*, *Mastogloia smithii*, *Pleurosira laevis*, *Diploneis smithii* and *Nitzschia amphibia*. The freshwater diatom taxa are distributed infrequently in the sediments stream of site 2, while they are commonly found in the sediments stream of site 15, where *Encyonemopsis microcephala* is dominant. But in overall, the recognized diatom assemblage reflects shallow, warm, mesotrophic, slightly brackish water conditions at both sites from the mouth of the Arer stream and Dhahadhhah stream, with an influence of freshwater from these streams, which may be loaded with some high metal concentrations and moderate nutrients matter.

Assemblage V was covering many sites from different three wadis, including Terbek stream (site 3), Wadi Souq stream (site 9) and Wadi Serhen stream (sites 10, 11, 14). The very good similarity between these sites is attributed to predominance of freshwater diatom taxa, in particular the tychoplanktonic *Synedra* ulna, which has maxima abundance ranges between 30 to 40% of the total assemblage. This species is considered as a freshwater form, common in meso- to eutrophic lakes and streams, epiphytic and benthic, with pH optimum is about 7.8 [51,85,72]. The diatom species association is represented in these sites by fairly common freshwater benthic forms such as *Navicula cincta, Navicula cryptocephala, Navicula rhynchocephala*, *Cymbella affinis, Cymbella amphicephala, Encyonema caespitosum, Encyonema minutum, Encyonema silesiacum, Encyonemopsis microcephala, Gomphonema gracile, Nitzschia frustulum* and *Nitzschia perminuta*. The brackish water and marine forms are distributed sparsely. The recognized freshwater taxa are similar to those reported from several freshwater environments in the world. The high abundance of benthic, mesotrophic and eutrophic freshwater diatom taxa, denote the high nutrients levels and the effects of freshwater influx and perhaps some sewage inflow to these studied wadis. Moreover, the occurrence of many eutrophic and mesosaprobic taxa may records the effect of human population growth with increasing sewering.

However, site 14 of Wadi Serhen stream is distinguished by abundance of *Tryblionella acuminate* (30%), which is not recorded in other sites. This species is recorded as a brackish water form, polyhalobous, meioeuryhaline, it usually inhabits the marine littoral zone, in waters with medium to high conductivities, pH and alkalinities [79,70,84]. Its occurrence abundantly with some other brackish water forms such as *Amphora coffeaeformis, Nitzschia amphibia, Nitzschia obtuse, Nitzschia scalaris* and *Tryblionella apiculata* indicative to slightly elevated salinity at this site in the middle part of the island.

Assemblage VI is characteristic of site 1, from Arer stream in the eastern part of Socotra Island. This site is distinguished from other sites of different streams by low diatom diversity and the dominant species is *Pleurosira laevis*, which has maximum abundance, reaches to 71% of the total assemblage. This species is a mesohalobous and characteristic of high brackish water conditions [79,86]. *Diploneis smithii* and *D. bombus* are relatively common (9%), and distinguish also high brackish water conditions and found in both brackish and coastal marine environments [80,53,81] The diatom association is represented by frequently occurrence of *Diploneis elliptica, Gomphonema gracile, Hantzschia virgata, Mastogloia dansei, Navicula rhynchocephala, Stenopterobia delicatissima* and *Synedra ulna*. *Hantzschia virgata* is regarded as being mesohalobous and prefers clean sandy shores to estuarine mud by [87,88]. The predominance of these taxa suggests high brackish water conditions with elevated salinity in the Arer stream. This may attributed to intrusion of the sea water into the Arer stream during period of rising sea level.

CONCLUSIONS

A detailed study on diatom assemblages separated from 15 samples collected from the surface sediments at different streams in Socotra Island revealed 145 diatom species belonging to 44 genera, which were the first record in the island. Multivariate statistical technique including Detrended correspondence and the cluster analyses were used to summarize changes in the diatom assemblages present in the examined streams. The results indicated six major diatom assemblages with variation in dominant species. Each assemblage reflects distinctive environmental conditions based on salinity preference of the recognized and dominant flora. It can be noted from the composition of the diatom assemblages found in the studied streams that most of the identified diatom flora prefer warm, eutrophic, slightly alkaline, freshwater and brackish conditions. The majority of the diatom species identified from streams sediments are common in eutrophic rivers. Most species identified are epilithic, but some are epipelic, and others are epiphytic species. A few species, such as *Cyclotella meneghiniana*, are typical of the plankton of larger rivers and lakes. The predominance of non-planktonic taxa compared to planktonic forms may be attributed to the shallowness of the environments with high nutrients levels.

The distribution pattern of recorded diatom flora and species composition showed differences the relative abundances between the studied streams. A number of taxa showed spatial variability, increasing in relative abundances in eastern streams. These include *Pleurosira laevis, Mastogloia braunii, Synedra ulna, Tryblionella granulata* and *Nitzschia frustulum*. While in the north-eastern streams *Staurosirella pinnata*, *Cocconeis placentula* and *Tryblionellagranulata* have maximum relative abundance. In the northern streams, the most dominant species are *Nitzschia frustulum, Nitzschia amphibia*, *Nitzschia perminuta, Navicula cryptocephala*, *Navicula cincta*, *Navicula cryptotenella*, *Navicula rhynchocephala*, *Encyonema caespitosum*, *Encyonema silesiacum, Synedra ulna, Tryblionella acuminata, Campylodiscus bicostatus* and *Amphora coffeaeformis*. However, *Encyonemopsis microcephala* was observed to be abundant in the western stream.

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