Original Research

Temporal variations in abundance and species richness of phytoplankton with emphasis on diatoms in the subtidal waters of Umm Al-Namil Island, north-western Arabian Gulf of the ROPME Sea Area

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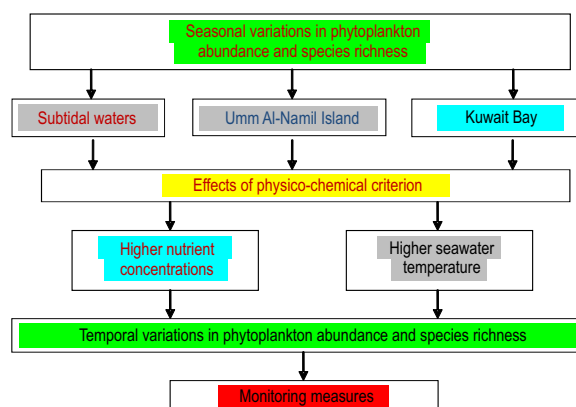
Abstract

Aim: The present study aimed to understand the physico-chemical factors affecting the abundance and species richness of phytoplankton communities, with emphasis on diatoms at the end of the intertidal zone and start of subtidal zone.

Methodology: Water quality and phytoplankton community species richness and abundance were measured in the subtidal waters of Umm Al-Namil Island, Kuwait Bay. Kruskal-Wallis statistical approach was used to measure the effect of various environmental parameters on abundance and species richness as well as abundance-species richness relationships using R statistical software.

Results: The physico-chemical parameters showed variations at each sampling event as well as within the same season. Total phytoplankton mean abundance values in summer (22.26 ± 0.66 ind. 5l^{-1}) and winter (21.63 ± 0.52 ind. 5l^{-1}) did not significantly vary and the lowest mean abundance was observed during spring (26.36 ± 0.33 ind. 5l^{-1}). Species abundance showed clear pattern with the events, resulting in somehow a negative relationship. Mean species richness was highest during autumn (24.59 ± 1.51), while no significant difference was observed between spring (11.09 ± 0.33), winter (10.47 ± 0.51) and summer (10.11 ± 0.66). The results indicate that phytoplankton species richness and species abundance in Umm Al-Namil Island varied temporally in response to fluctuations in environmental conditions.

Interpretation: The end of intertidal zone and beginning of subtidal zone is affluent in diverse forms of phytoplankton species, specifically diatoms since Kuwait Bay is a eutrophic area mainly due to sewage and urbanization. Therefore, a temporal monitoring is required in order to observe any changes in either physico-chemical or biological factors with time and that will help in future conservation and restoration programs. Conservation approaches should be considered seriously since some diatoms like *Melosira moniliformis, Gyrosigma diminutum, Fragilaria martyi, Hemidiscus cuneiformis, Planktoniella sol* and *Amphiprora plicata* have been observed only at one event despite abundance and season.

Key words: Kuwait Bay, Phytoplankton, Species richness, Subtidal waters, Umm Al-Namil Island

Seasonal variations in phytoplankton abundance and species richness

Subtidal waters | Umm Al-Namil Island | Kuwait Bay

Effects of physico-chemical criterion

Higher nutrient concentrations | Higher seawater temperature

Temporal variations in phytoplankton abundance and species richness

Monitoring measures

Introduction

Phytoplankton plays a vital role in maintaining the ecological evenness of the coastal ecosystems for sustaining all other forms of life by producing oxygen and food (Khan, 2003). Understanding the abundance, the community composition of phytoplankton can contribute further perceptive of structure and functioning of pelagic ecosystem and benefit in administration of fisheries. Biodiversity is an imperative prerequisite for the preservation of ecosystem maintenance providing diversified assistance to human prosperity (Hoekstra *et al.*, 2012). With relevance to phytoplankton biodiversity, these assistances may reach from encouraging primary productivity and supplies food (via the trophic cascade) to coordinate water quality and climate (e.g., via nutrient and carbon fixation, oxygen production), in addition to creative and health form (e.g., preventing cyanobacteria influence and blooms in water bodies used for recreational purposes). Besides, biodiversity curtails adverse feedback to environmental changes by strengthening the resistance and flexibility of ecosystems (McNaughton, 1977; Naeem and Li 1997; Chapin *et al.,* 2000).

Nonetheless, biodiversity is drop off at a speedy dimension (Hooper *et al.* 2005; Worm *et al.,* 2006) and this decrease is further increased by man-made climate change and related increasing temperatures on a comprehensive proportion (Lovejoy and Hannah 2006; IPCC 2007). The perception of phytoplankton distribution with implication to spatial pattern is important to persuade the status of the ecosystem structure and functioning.The spatial mapping of phytoplankton assists to resolve hotspots established on abundance and diversity (Badsi *et al.,* 2012; Nassar and Hgarib, 2014; Ahmed and Wanganeo, 2015). Measures of diversity are periodically seen as indicators of the stature of ecological systems. Phytoplankton diversity has relevance with yield in ecology (Newall *et al.,* 2011; Vallina *et al.,* 2014). In extent, the diversity index may be used for habitat characterization (de Domitrovic and de Neiff, 2007; Polikarpov *et al,* 2008; Cardoso *et al.,* 2012). Phytoplankton patterning varies across ecosystems, have large year-to-year alternation, and display annual cycles of biomass fluctuation and habituation strength (Scheffer 1991; Winder and Cloern 2010; Al-Yamani *et al.,* 2017; Devlin *et al.,* 2019).

Temperature is an important parameter controlling phytoplankton production rates, nutrient utilization, and spatial and temporal distribution in marine systems. In extension to aspects such as grazing pressure or nutrient availability, phytoplankton taxa react adversely to various temperature systems (Canale and Vogel, 1974; Butterwick *et al.,* 2005). With overall average surface temperatures envisaged to increase by 1.1–6.4 °C within the next 100 years (IPCC 2007), water temperatures will benefit this tendency, leading to alteration in the thermal system of many seawater habitats (Webb and Nobilis 2007) and strengthen transition in both phytoplankton community arrangement and distribution in markedly sensitive ecosystems like modest water bodies or tiny islands.

This study was performed during low tide at the start of the subtidal zone (the area at the end of the intertidal zone where subtidal waters start) to 10 cm depth off Umm Al -Namil Island, as it forms an important transition area between intertidal and subtidal zones. The aim of the study herein was to understand the physico-chemical factors affecting the abundance and species richness of phytoplankton at the end of the intertidal zone and the start of subtidal zone off Umm Al-Namil Island.

Materials and Methods

Site description: Umm Al-Namil Island (29°22'43.4496"N 47°52'4.3176"E) is one of the small islands among the nine islands present within the territorial waters of Kuwait in the north-western part of the Arabian (= Persian) Gulf of the ROPME (Regional Organization for the Protection of the Marine Environment) Sea Area. ROPME Sea Area is divided into three sub-areas: inner, middle and outer sea areas. The study area herein lies within the inner ROPME Sea Area. The island is around 600 m away from Kuwait mainland. It is situated at the southwestern corner of Kuwait Bay along the northwestern side of Sulaibikhat Bay (Fig. 1). It is oriented in a northeast-southwest direction and has a drumstick shape (Al- Zamel *et al.,* 2007).

The island narrows to 75 m in the southwestern side and is approximately 800 m long and 300 m wide at the eastern side. Along the eastern side of the main tidal channel of the island, the maximum water depth is about 4-5 m (Al- Zamel *et al.,* 2007). The island is bounded by well-developed tidal flats. Supratidal flats consist of gypsum and anhydrite, which form most of the coastal dunes in the area and the intertidal flat is hard and accompanied by oyster mounds, whereas the subtidal flat is soft muddy sand with high productivity (Al- Zamel *et al.,* 2007).

Sampling and analysis: Phytoplankton samples were collected during the period 2016-2017 at monthly intervals covering 4 seasons representing autumn (October and November), winter (December, January, and February), spring (March and April), and summer (May, June, July, August and September). Sampling was performed during low tide at the start of the subtidal zone (the area at the end of the intertidal zone where subtidal waters start) at depth up to 10 cm off Umm Al-Namil Island. A unique number was assigned for each sampling (Table 1).

Samples were collected in one-liter sampling bottle and poured into a 20-microns mesh for five times. Samples preserved in glutaraldehyde-formaldehyde solution (1:1 vol) were allowed to settle for 48hrs in 1.5l measuring cylinders. The settling and siphoning procedure (Utermöhl, 1958) with settling chambers were used for microscopic analysis of plankton samples. Organisms collected from 25 ml out of 100 ml of the concentrated bottom samples were further settled on 25 ml Utermöhl chambers for another 24 hrs before carriying out the taxonomic analysis. A 25 ml sub-sample was poured into a settling chamber, and left to

settle for 24 hrs. The base plate was then removed from the chamber and a slide placed over the top of the base plate into which the planktonic organisms had settled. The samples were enumerated using a Leica inverted microscope (model number DMi1). The counting and identification of phytoplankton was carried out based on the method reported by Tomas (1997).

The abundance of each plankton was calculated as individuals presente in 5 l (ind. $5l^{-1}$), since 5 liters of water were collected and filtered through 20μ mesh as explained above to catch the phytoplankton for this study. All individuals in the samples were counted and identified. Water temperature, pH, salinity, dissolved oxygen were measured in the subtidal sampling location using amultiparameter field meter (Orion Star A326, Thermo-Fisher Scientific STARA3260 series). Water samples were collected and brought back to the laboratory for nutrient analysis, *i.e.*, nitrate (NO_3), nitrite (NO_2), phosphate (PO_4) and Silicates (SiO_4). Standard analytical procedures (MOOPAM, 2010) were used for measuring the concentrations of the aforementioned nutrients using the UV-Vis Spectrophotometer (Beckman coulter A23615 Du 720 General-Purpose Spectrophotometer).

Statistical analyses: A non-parametric Kruskal-Wallis statistical approach was used to test the effect of various environmental parameters on abundance and species richness as well as abundance-species richness relationships using R statistical software version 3.2.3 (R Core Team, 2016).

Results and Discussion

The physico-chemical parameters varied within the same sampling season at each sampling event (Fig. 2 and 3). Dissolved oxygen (DO) concentration ranged between 5 mg l^{-1} in winter (at event 5 and 6) to 8.2 mg l^{-1} (at events 4 in winter and 12 in summer) (Fig. 2A). The highest mean concentration of DO was observed during autumn (7.59 ± 0.029 mg l^{-1}), while the lowest was observed during winter (5.75 ± 0.25 mg l^{-1}) (Fig. 3C). However, the mean DO value in winter did not significantly differ from that of summer (6.49 ± 0.11 mg l^{-1}) and spring (6.16 ± 0.087 mg l^{-1}) (Fig.
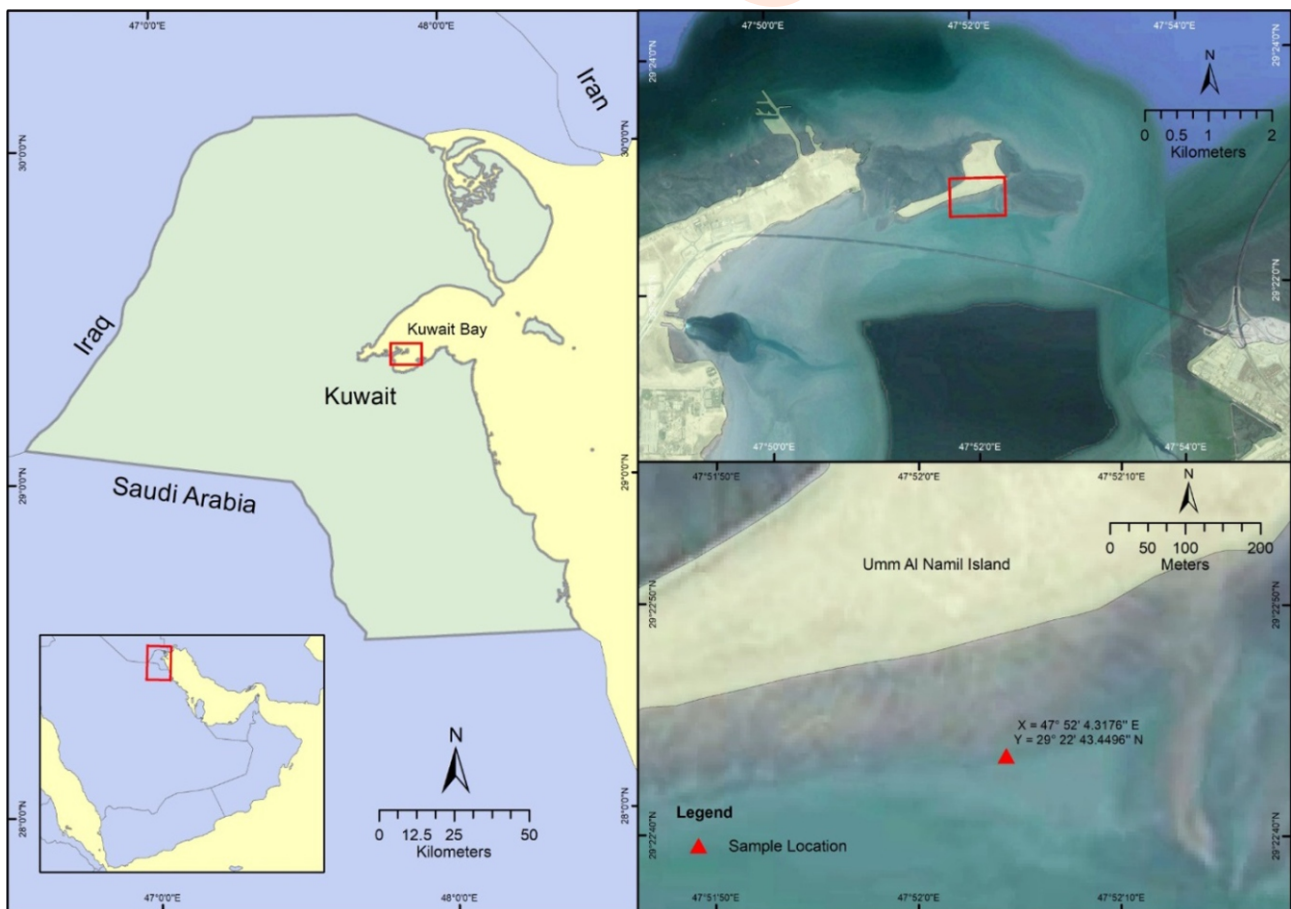
Fig. 1: Map of Kuwait showing the location of Umm Al-Namil Island in Kuwait Bay, North-western Arabian (= Persian) Gulf, along with the sampling location represented by a red triangle at the start of the subtital zone (29°22'43.4496"N 47°52'4.3176"E) during low tide.

Table 1: Sampling months during the study period in the subtidal area of Umm Al-Namil Island. The "Event" column refers to sampling event. Each event has been assigned a unique number that refers to the month and year where sampling occurred. This was done in order to make figure representation tidier. Table also shows seasons related to each month

Month, Year	Season	Event
September, 2016	Summer	1
October,2016	Autumn	2
November, 2016	Autumn	3
December, 2016	Winter	4
January, 2017	Winter	5
February,2017	Winter	6
March, 2017	Spring	7
April, 2017	Spring	8
May, 2017	Summer	9
June, 2017	Summer	10
July, 2017	Summer	11
August,2017	Summer	12

3C). Sea surface temperature (SST) ranged between 7.2 to 29.4°C at events 4 and 11 in winter and summer, respectively (Fig. 2B). A consistent pattern of variations in SST was visible within the season (Fig. 2B, 3A). The mean SST was 29.10 ± 0.11, 21.36 ± 0.029, 17.82 ± 0.087, 9.51 ± 0.25 °C in summer, autumn, spring, and winter, respectively (Fig. 3A).

Salinity ranged between 42 to 47.1 psu at events 3 and 12 during autumn and summer, respectively (Fig. 2C). Salinity did not significantly vary among spring (45.96 ± 0.15 psu), summer (45.79 ± 1.67psu), and winter (44.29 ± 0.98psu), but was lowest during autumn (42.16 ± 0.15psu) (Fig. 3B). The pH values ranged between 5.2 to 10 at events 4 and 8 during winter and spring seasons (Fig. 2D). The pH level was highest during spring (9.73 ± 0.054) compared to other seasons, which did not significantly vary 6.74 ± 0.072, 6.15 ± 0.054, and 5.66 ± 0.047 during summer, winter, and autumn, respectively) (Fig. 2D, 3D). Nitrate level ranged from 0.02 (events 6 in winter and 7 in spring) to 0.8 mg l^{-1} at event 4 in winter (Fig. 2E). The level of nitrate was almost same throughout the events 2, 6-12 (Fig. 2E) without significant variations unlike events 1, 3, 4-5 (Fig. 2E). Nitrate levels were highest during winters 0.38 ± 0.58 mg l^{-1} at and lowest in spring being near zero, with no significant difference between autumn (0.16 ± 0.019 mg l^{-1}) and summer (0.17 ± 0.016 mg l^{-1}) (Fig. 2E). Phosphates showed almost a consistent pattern with events but the lowest value was observed in summer at events 9 and 10 being 0.19 mg l^{-1} and highest value was observed at event 6 in winter being 0.7 mg l^{-1} (Fig. 2F). Generally, the level of phosphates varied with season being, 0.465 ± 0.0371 mg l^{-1} (winter), 0.20 ± 0.011 mg l^{-1} (autumn), 0.23 ± 0.011 mg l^{-1} (summer), and 0.196 ± 0.0011 mg l^{-1} (spring) (Fig. 2F, 3H) but was highest in winter being 0.5 ± 0.058 mg l^{-1} (Fig. 2F, 3H).

Silicates did not show a consistent pattern with events but it was highest at event 12 in summer (2.71 mg l^{-1}) and lowest at

event 6 in winter (0.61 mg l^{-1}) (Fig. 2G). Highest mean level of silicates was observed during autumn (0.95 ± 0.016 mg l^{-1}) and lowest during winter (1.032 ± 0.079 mg l^{-1}), however, no significant variation between summer (2.17 ± 0.077 mg l^{-1}) and spring (1.55 ± 0.020 mg l^{-1}) (Figs. 2G, 3E). Nitrites were lowest in autumn at events 2 and 3 with the same value (0.02 mg l^{-1}), while the highest value (0.58 mg l^{-1}) was recorded at event 4 in winter (Fig. 2H). There was no significant difference in mean nitrites level between summer (0.077 ± 0.004 mg l^{-1}) and spring (0.073 ± 0.0023 mg l^{-1}) (Fig. 2H, 3G). Phytoplankton abundance (ind. 5 l^{-1}) was highest at event 2 in autumn (50 ind. 5l^{-1}) and lowest at event 12 in summer (13 ind. 5l^{-1}) (Fig. 2I). Mean abundance was highest during autumn (48.59 ± 0.22ind. 5l^{-1}), followed by spring (26.36 ± 0.33 ind. 5l^{-1}). Mean phytoplankton abundance during summer (22.26 ± 0.66 ind. 5l^{-1}) and winter (21.63 ± 0.52 ind. 5l^{-1}) did not significantly vary, and the lowest mean abundance was observed in the latter season (Fig. 2I). Species richness was highest at event 2 (autumn) being 50, while the lowest species richness was observed in summer at event 12 being 3 (Table 5, Fig. 2 J). Mean species richness was highest during autumn (24.59 ± 1.51), while no significant difference was observed between spring (11.09 ± 0.33), winter (10.47 ± 0.51), and summer (10.11 ± 0.66) (Fig. 3J). Like abundance, the values of species richness at events 5 to 10 did not significantly vary, and both richness and abundance were lowest at event 12 in summer (Fig. 2I,J). Both species richness and abundance had significantly varied with season (Fig. 2I, J).

The effect of season as well as the effect of physico-chemical parameters was significant on both abundance and species richness of different phytoplankton groups (Tables 3-5). The effect of abundance on species richness was significant, and the maximum percentage of diatom observed was 92% and the lowest was 38.46% (Fig 5). Previous studies on the Arabian Gulf showed that it is exposed to potential impacts by recent urban developments (Ibrahim and El Samra, 1987; Al-Muzaini and Jacob, 1996; Subba-Rao *et al.,* 1999; Nour El-Din and Al-Khayat, 2005; QMEMP, 2005; Sheppard *et al.,* 2010; Al-Yamani *et al.,* 2017; Devlin *et al.,* 2019), also, nitrogen limitation plays a role in the functioning of this ecosystem (Quigg *et al.,* 2013).

The Arabian Gulf ecosystem is currently facing loss of precise habitat to development, pollution due to discharge of toxic chemicals by industry, with particularly the ones relevant to oil exploration, invasive species from ballast waters, and eutrophication (e.g., Ibrahim and El Samra, 1987; Al-Muzaini and Jacob, 1996; Subba-Rao *et al.,* 1999; Nour El-Din and Al-Khayat, 2005; Qatar Marine Environment Monitoring, 2005; Sheppard *et al.,* 2010). Over-and-above, "brine" discharged from desalination plants with salinities > 75 psu will escalate salinity in most hypersaline water bodies (Abdul Azis *et al.,* 2003; Lattemann and Hopner, 2008; Sheppard *et al.,* 2010). So, increased salinity could lead to higher phytoplankton diversity but lower biomass and lower production (Polikarpov *et al.,* 2008). Succession of phytoplankton species composition was observed and it was due to the changes in the physico-chemical

Table 2: Kruskal-Wallis test showing the effect of season, seawater temperature, salinity, dissolved oxygen concentration, nitrates, nitrites, phosphates, and silicates on phytoplankton abundance. The effect of season on abundance was significant (Chi-Square = 109.16, df = 3, p = 2.2 x 10^{-16}), as well as the effect of temperature on the abundance (Chi-Square = 145, df = 11, p = 2.2 x 10^{-16}). The effect of salinity on abundance was also significant (Chi-Square = 145, df = 11, p = 2.2 x 10^{-16}), as well as the effect of dissolved oxygen on abundance (Chi-Square= 138.19, df = 9, p = 2.2 x 10^{-16}). The effect of pH was also significant (Chi-Square= 134.6, df = 9, p = 2.2 x 10^{-16}) along with those of nitrates (Chi-Square=60.713, df = 6, p = 3.224 x 10^{-11}), nitrites (Chi-Square= 128.26, df = 8, p = 2.2 x 10^{-16}), silicates (Chi-Square= 81.528, df = 10, p = 2.518 x 10^{-13}), and phosphates (Chi-Square= 76.454, df = 4, p = 9.814 x 10^{-16})

Explanatory Variable	Chi-Square	DF	P
Season	109.16	3	2.2 x 10^{-16} S
Temperature	145	11	2.2 x 10^{-16} S
Salinity	145	11	2.2 x 10^{-16} S
Dissolved Oxygen	138.19	9	2.2 x 10^{-16} S
pH	134.6	9	2.2 x 10^{-16} S
Nitrates	60.713	6	3.224x10^{-11} S
Nitrites	128.26	8	2.2 x 10^{-16} S
Phosphates	76.454	4	9.814 x 10^{-16} S
Silicates	81.528	10	2.518 x 10^{-13} S

Significance codes of p values: S= significant, N= not significant

Table 3: Kruskal-Wallis test showing the effect of season, seawater temperature, salinity, dissolved oxygen concentration, nitrates, nitrites, phosphates, and silicates on phytoplankton species richness. The effect of season on species richness was significant (Chi-Square = 99.435, df = 3, p = 2.2 x 10^{-16}), as well as the effect of temperature on the species richness (Chi-Square = 145, df = 11, p = 2.2 x 10^{-16}). The effect of salinity on species richness was also significant (Chi-Square = 145, df = 11, p = 2.2 x 10^{-16}), as well as the effect of dissolved oxygen on species richness (Chi-Square= 39.28, df = 8, p = 4.368 x 10^{-06}). The effect of pH was also significant (Chi-Square= 130.65, df = 9, p = 2.2 x 10^{-16}) along with those of nitrates (Chi-Square=94.832, df = 6, p = 2.2 x 10^{-16}), nitrites (Chi-Square= 125.55, df = 8, p = 2.2 x 10^{-16}), silicates (Chi-Square= 113.83, df = 10, p = 2.2 x 10^{-16}) and phosphates (Chi-Square= 67.022, df = 4, p = 9.645 x 10^{-14})

Explanatory Variable	Chi-Square	DF	P
Season	99. 435	3	2.2 x 10^{-16} S
Temperature	145	11	2.2 x 10^{-16} S
Salinity	145	11	2.2 x 10^{-16} S
Dissolved oxygen	143.15	9	2.2 x 10^{-16} S
pH	130.65	9	2.2 x 10^{-16} S
Nitrates	94.832	6	2.2 x 10^{-16} S
Nitrites	125.55	8	2.2 x 10^{-16} S
Phosphates	67.022	4	9.645x 10^{-14} S
Silicates	113.83	10	2.2 x 10^{-16} S

Significance codes of p values: S= significant, N= not significant

Table 4: Kruskal-Wallis test showing the effect of abundance on species richness and vice versa. The effect of abundance on species richness was significant (Chi-Square = 125.04, df = 8, p = 2.2 x 10^{-16}), as well as the effect of species richness on abundance (Chi-Square = 128.31, df = 7, p = 2.2 x 10^{-16})

Explanatory Variable	Chi-Square	DF	P
Abundance	125.04	8	2.2 x 10^{-16} S
Species Richness	128.31	7	2.2 x 10^{-16} S

Significance codes of p values: S= significant, N= not significant

aspects of the water (Buzzi, 2002; Touliabah *et al.,* 2016). Water temperature in the present study was obviously lower in winter (7.2°C) compared to summer (29.4°C).

The temperature values recorded during spring and summer appeared to be suitable for phytoplankton growth,

where phytoplankton species richness reached its maximum value. These data are in conformity with those of Boyd *et al.* (2013), who recorded that the optimal temperature for phytoplankton growth is 10-33.2°C. In the present study, the water around Umm Al Namil Island was alkaline. (Fig. 2D; 3D), where it ranged between 8.2 in autumn and 8.6 in winter.

Table 5: List of phytoplankton found at each sampling event (month) in this study with total abundance, species richness and individual species abundance. The abundance is estimated as individual per 5 liters (ind 5l⁻¹). Table also shows the season that coincided with every month

Month. Year	Event	Season	Species	Individual abundance species	Group	Species richness
Sept. 2016	1	Summer	*Chaetoceros affinis*	1	Diatoms	
			Navicula directa	2	Diatoms	**11 Total**
			Cyclotella stylorum	2	Diatoms	**abundance**
			Ditylum brightwellii	3	Diatoms	**27**
			Biddulphia pulchella	3	Diatoms	
			Bacillaria paxillifera	3	Diatoms	
			Amphora sulcata	2	Diatoms	
			Cylindrotheca closterium	2	Diatoms	
			Trichodesmium erythraeum	6	Cyanobacteria	
			Ceratium tripos	1	Dinoflagellates	
			Noctiluca scintillans	2	Diatoms	
Oct. 2016	2	Autumn	*Navicula directa*	3	Diatoms	**Species richness**
			Nitzschia longissima	2	Diatoms	**26 Total**
			Guinardia flaccida	3	Diatoms	**abundance**
			Coscinodiscus centralis	2	Diatoms	**50**
			Melosira moniliformis	2	Diatoms	
			Bellerochea horologicalis	2	Diatoms	
			Lauderia annulata	1	Diatoms	
			Thalassiosira eccentrica	3	Diatoms	
			Thalassiothrix longissima	1	Diatoms	
			Leptocylindrus danicus	3	Diatoms	
			Odontella mobiliensis	3	Diatoms	
			Gyrosigma diminutum	1	Diatoms	
			Ditylum brightwellii	1	Diatoms	
			Biddulphia pulchella	3	Diatoms	
			Triceratium reticulum	2	Diatoms	
			Pseudonitzschia delicatissima	1	Diatoms	
			Corethron criophilum	1	Diatoms	
			Licmophora abbreviata	2	Diatoms	
			Amphora sulcata	1	Diatoms	
			Scenedesmus quadricauda	2	Diatoms	
			Cylindrotheca closterium	1	Diatoms	
			Pediastrum duplex var. clathratum	2	Diatoms	
			Trichodesmium erythraeum	1	Cyanobacteria	
			Oscillatoria nigroviridis	3	Cyanobacteria	
			Ceratium tripos	1	Dinoflagellates	
			Noctiluca scintillans	3	Dinoflagellates	
Nov. 2016	3	Autumn	*Navicula directa*	2	Diatoms	**Species richness**
			Guinardia flaccida	3	Diatoms	**23 Total**
			Cyclotella stylorum	2	Diatoms	**abundance**
			Bellerochea horologicalis	2	Diatoms	**47**
			Lauderia annulata	1	Diatoms	
			Thalassiosira eccentrica	5	Diatoms	
			Thalassiothrix longissima	2	Diatoms	
			Leptocylindrus danicus	2	Diatoms	
			Odontella mobiliensis	2	Diatoms	
			Pleurosigma elongatum	2	Diatoms	
			Fragilaria martyi	2	Diatoms	
			Ditylum brightwellii	1	Diatoms	
			Bacillaria paxillifera	2	Diatoms	
			Triceratium reticulum	2	Diatoms	
			Corethron criophilum	2	Diatoms	

			Skeletonema costatum	1	Diatoms	
			Licmophora abbreviata	1	Diatoms	
			Scenedesmus quadricauda	1	Diatoms	
			Cylindrotheca closterium	2	Diatoms	
			Pediastrum duplex var. clathratum	3	Diatoms	
			Trichodesmium erythraeum	2	Cyanobacteria	
			Oscillatoria nigroviridis	2	Cyanobacteria	
			Ceratium tripos	3	Dinoflagellates	
Dec. 2016	4	Winter	*Guinardia flaccida*	5	Diatoms	**Species richness**
			Bellerochea horologicalis	2	Diatoms	**7 Total**
			Thalassionema nitzschioides	6	Diatoms	**abundance**
			Trichodesmium erythraeum	2	Diatoms	**20**
			Lyngbya majuscula	1	Cyanobacteria	
			Protoperidinium murrayi	1	Dinoflagellates	
			Dinophysis caudata	3	Dinoflagellates	
Jan. 2017	5	Winter	*Navicula directa*	2	Diatoms	**Species richness**
			Nitzchia longissima	2	Diatoms	**11 Total**
			Cyclotella stylorum	1	Diatoms	**abundance**
			Bellerochea horologicalis	2	Diatoms	**19**
			Thalassionema nitzschioides	1	Diatoms	
			Pleurosigma elongatum	1	Diatoms	
			Ditylum brightwellii	1	Diatoms	
			Trichodesmium erythraeum	3	Cyanobacteria	
			Protoperidinium murrayi	2	Dinoflagellates	
			Ceratium tripos	2	Dinoflagellates	
			Gymnodinium gracilentum	2	Dinoflagellates	
Feb. 2017	6	Winter	*Bacteriastrum delicatulum*	1	Diatoms	**Species richness**
			Navicula directa	4	Diatoms	**11 Total**
			Guinardia flaccida	1	Diatoms	**abundance**
			Bellerochea horologicalis	3	Diatoms	**25**
			Thalassiosira eccentrica	3	Diatoms	
			Biddulphia pulchella	1	Diatoms	
			Hemidiscus cuneiformis	1	Diatoms	
			Amphiprora plicata	1	Diatoms	
			Amphora sulcata	2	Diatoms	
			Hemiaulus sinensis	3	Diatoms	
			Trichodesmium erythraeum	2	Cyanobacteria	
			Protoperidinium murrayi	3	Diatoms	
Mar. 2017	7	Spring	*Chaetoceros affinis*	1	Diatoms	**Species richness**
			Navicula directa	2	Diatoms	**11 Total**
			Pseudonitzschia delicatissima	2	Diatoms	**abundance**
			Ditylum brightwellii	2	Diatoms	**25**
			Biddulphia pulchella	3	Diatoms	
			Bacillaria paxillifera	4	Diatoms	
			Amphora sulcata	2	Diatoms	
			Hemiaulus sinensis	4	Diatoms	
			Trichodesmium erythraeum	1	Cyanobacteria	
			Ceratium tripos	2	Dinoflagellates	
			Dinophysis caudata	1	Dinoflagellates	
			Prorocentrum micans	1	Dinoflagellates	
Apr. 2017	8	Spring	*Bacteriastrum delicatulum*	2	Diatoms	**Species richness**
			Coscinodiscus centralis	3	Diatoms	**11 Total**
			Thalassionema nitzschioides	2	Diatoms	**abundance**
			Pseudonitzschia delicatissima	2	Diatoms	**28**
			Asterionellopsis glacialis	2	Diatoms	
			Licmophora abbreviata	4	Diatoms	
			Amphora sulcata	2	Diatoms	
			Trichodesmium erythraeum	7	Cyanobacteria	

Table continue

|						
			Ceratium tripos	2	Dinoflagellates	
			Dinophysis caudata	2	Dinoflagellates	
May. 2017	9	Summer	*Chaetoceros affinis*	1	Diatoms	**Species richness**
			Pseudonitzschia delicatissima	1	Diatoms	**13 Total**
			Thalassiosira eccentrica	1	Diatoms	**abundance**
			Bacillaria paxillifera	1	Diatoms	**20**
			Asrerionellopsis glacialis	3	Diatoms	
			Planktoniella sol	1	Diatoms	
			Diploneis weissflogii	3	Diatoms	
			Amphora sulcata	1	Diatoms	
			Pediastrum duplex var. clathratum	1	Cyanobacteria	
			Oscillatoria nigroviridis	2	Cyanobacteria	
			Lyngbya majuscula	2	Diatoms	
			Ceratium tripos	2	Diatoms	
			Prorocentrum micans	1	Diatoms	
Jun. 2018	10	Summer	*Cyclotella stylorum*	1	Diatoms	**Species richness**
			Thalassiosira eccentrica	1	Diatoms	**10 Total**
			Bacillaria paxillifera	3	Diatoms	**abundance**
			Asrerionellopsis glacialis	4	Diatoms	**26**
			Diploneis weissflogii	4	Diatoms	
			Dunaliella bioculata	1	Chlorophyta	
			Oscillatoria nigroviridis	5	Cyanobacteria	
			Lyngbya majuscula	4	Cyanobacteria	
			Ceratium tripos	1	Dinoflagellates	
			Prorocentrum micans	2	Dinoflagellates	
Jul. 2018	11	Summer	*Cyclotella stylorum*	2	Diatoms	**Species richness**
			Thalassiosira eccentrica	3	Diatoms	**7 Total**
			Asrerionellopsis glacialis	2	Diatoms	**abundance**
			Diploneis weissflogii	3	Diatoms	**19**
			Dunaliella bioculata	1	Chlorophyta	
			Lyngbya majuscula	5	Cyanobacteria	
			Protoperidinium murrayi	3	Dinoflagellates	
Aug. 2017	12	Summer	*Diploneis weissflogii.*	5	Diatoms	**Species richness**
			Dunaliella bioculata	1	Chlorophyta	**4 Total**
			Lyngbya majuscula	4	Cyanobacteria	**abundance**
			Dinophysis caudata	3	Dinoflagellates	**13**

These pH values are suitable for high phytoplankton standing crop, which produced highest value in the same season where diatoms, dinoflagellates and blue-green algal species showed maximum growth above pH 8. Similar observations were also reported by Touliabah *et al.* (2010) and El Gammal (2017) in the coastal waters of Saudi Arabia. Such high pH values in this study could be due to higher photosynthetic consumption of carbon dioxide (Hinga, 2002).

The DO behavior in this study being higher during autumn, summer, and spring compared to winter as explained earlier may be due to increased SST and breakdown of planktonic organisms, organic matter, and detritus where oxygen is consumed and carbon dioxide is released. This shows that oxygen solubility decreases with rising salinity and temperature (Calliari *et al.,* 2005). Wide inconstancies in temperature were observed between winter and summer. The wide-ranging seasonal discrepancy in temperature in coastal water (Abdul Azis *et al.,* 2003) is considerably an impact of stern weather of the

study area and strident condition of the Gulf region (Price, 1979). Arabian Gulf is a semi-enclosed system where evaporation is one of the most valuable and substantial factor that changes the salinity. There was no such huge variation in salinity, that exhibits the highest value (47.1 psu) during summer and the lowest values (42.0 psu) during autumn (Fig. 2C). Higher salinity values during summer may be associated to excessive evaporation rate as stated by Khomayis (2002) and Schumann *et al.* (2006). In the present study (Table 3), the effect of salinity on species richness was significant. Schumann *et al.* (2006) demonstrated that salinity affects the phytoplankton diversity. It has been reported that increasing salinity rises phytoplankton diversity but lowers both phytoplankton biomass and production further, Polikarpov *et al.* (2008). Thus, more studies have to be conducted near Umm Al-Namil Island in future.

The present investigation data revealed that the lowest phosphate concentration (0.19 mg kg^{-1}) was observed during summer, while the highest during autumn (0.7 mg kg^{-1}; Fig. 2F).
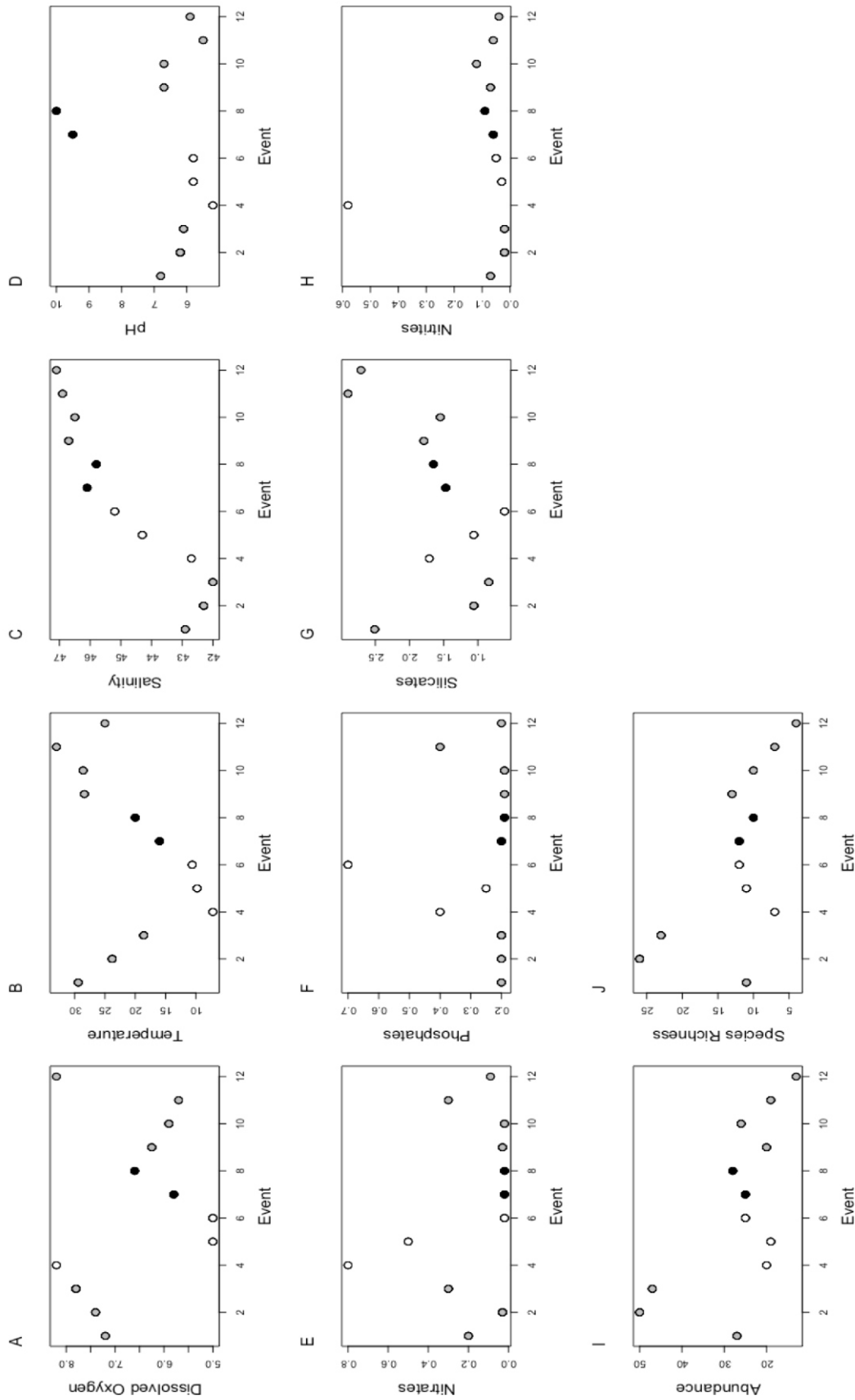
Fig. 2: Physico-chemical and biological parameters at each sampling event (Event) as explained in Table 1 in the subtidal water of Umm Al-Namil Island. (A) Dissolved oxygen concentration (mg l⁻¹), (B) Seawater temperature (°C); (C) Salinity (PSU); (D) pH; (E) Nitrates (mg kg⁻¹); (F) Phosphates (mg kg⁻¹); (G) Silicates (mg kg⁻¹); (H) Nitrites (mg kg⁻¹); (I) Phytoplankton abundance (individual. 5 l⁻¹) and (J) Species richness (S). Colours represent seasons as follows: White for winter, black for autumn, light grey for spring and dark grey for summer.
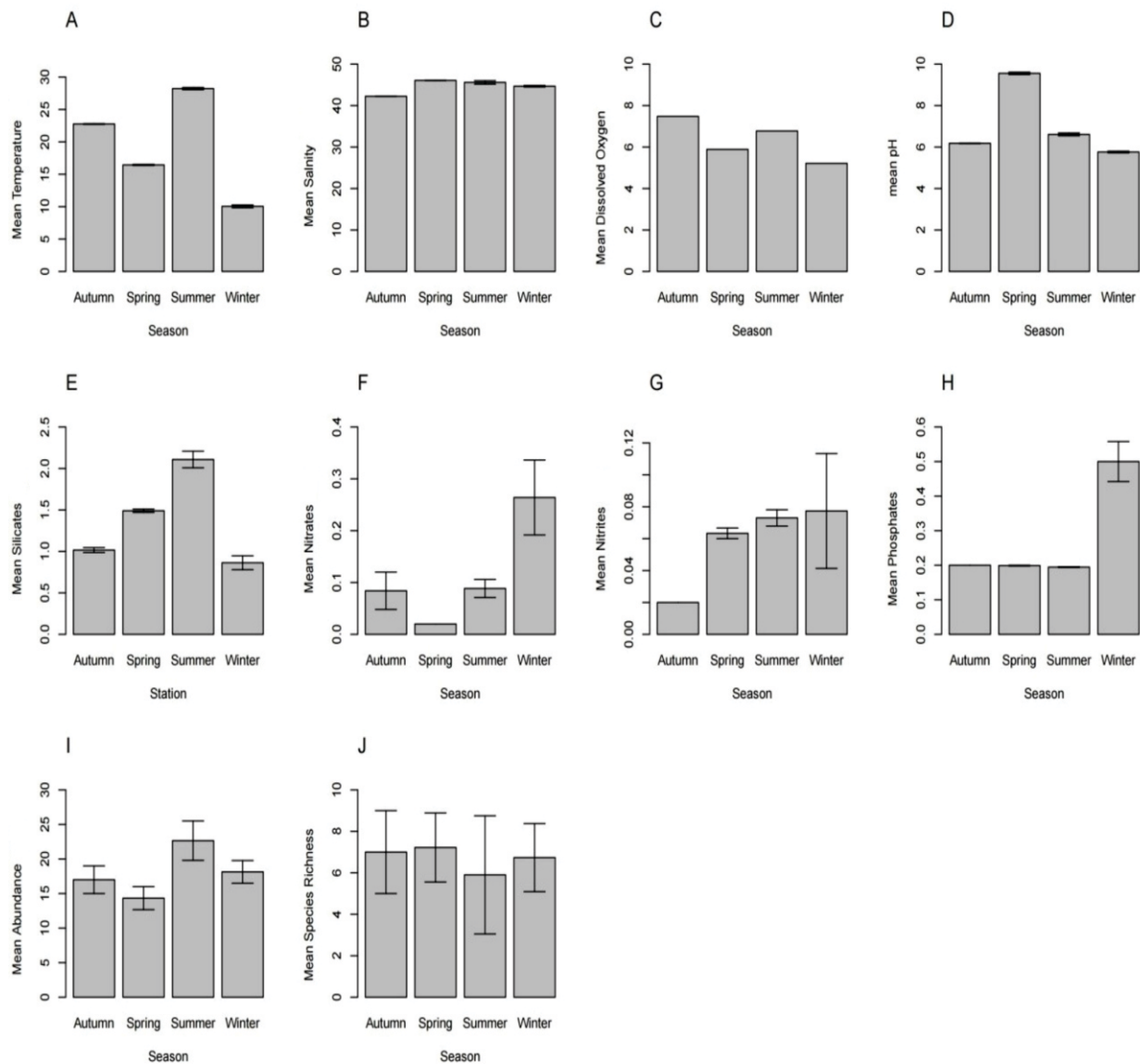
Fig. 3: Mean values with standard error bars for physico-chemical and biological parameters at each season in the subtidal water of Umm Al-Namil Island. (A) Seawater temperature (°C); (B) Salinity (PSU); (C) Dissolved oxygen concentration (mg l^{-1}); (D) pH; (E) Silicates (mg kg^{-1}); (F) Nitrates (mg kg^{-1}); (G) Nitrites (mg kg^{-1}); (H) Phosphates (mg kg^{-1}); (I) Abundance (individual. 5 l^{-1}) and (J) Species richness (S). Unseen error bars due to small variation in data.

This could be related to reduced uptake rates by phytoplankton in summer than autumn; this was confirmed by the reduced phytoplankton standing crop recorded during summer compared with autumn where phosphate reached its lowest value (Touliabah *et al.,* 2016). Nitrite (0.58 mg kg^{-1}) and silicate (0.95 mg kg^{-1}) attained their maximum values in winter and autumn, while the minimum value (0.02 mg kg^{-1} and 0.61 mg kg^{-1}) was observed during winters for both nitrite and silicate, respectively. Nitrate reached its maximum value (0.26 mg kg^{-1}) during spring, and minimum (0.16 mg kg^{-1}) during winter and summer with similar values. In this study, higher levels of nitrite, nitrate and silicates were observed due to discharge of domestic waste waters in

around the area. Normally, nitrogen and phosphorous are present in the domestic waste waters (El-Bassat and Taylor, 2007), hence, presence of both are presumed in the waters of study area. A total of 46 species belonging to 4 groups were identified from the water of Umm Al-Namil Island. Bacillariophyceae were frequently present (72%) comprising Dinophyceae, Cyanophyceae and Chlorophyceae (13%, 7% and 8%) respectively. The most abundant phytoplankton was observed during October (autumn), while minimum during August (summer). This was also observed by Abdulaziz *et al.* (2000) in the coastal waters of Saudi Arabia. During autumn, phytoplankton peaks were primarily due to the presence of Dinophyceae,

A

B
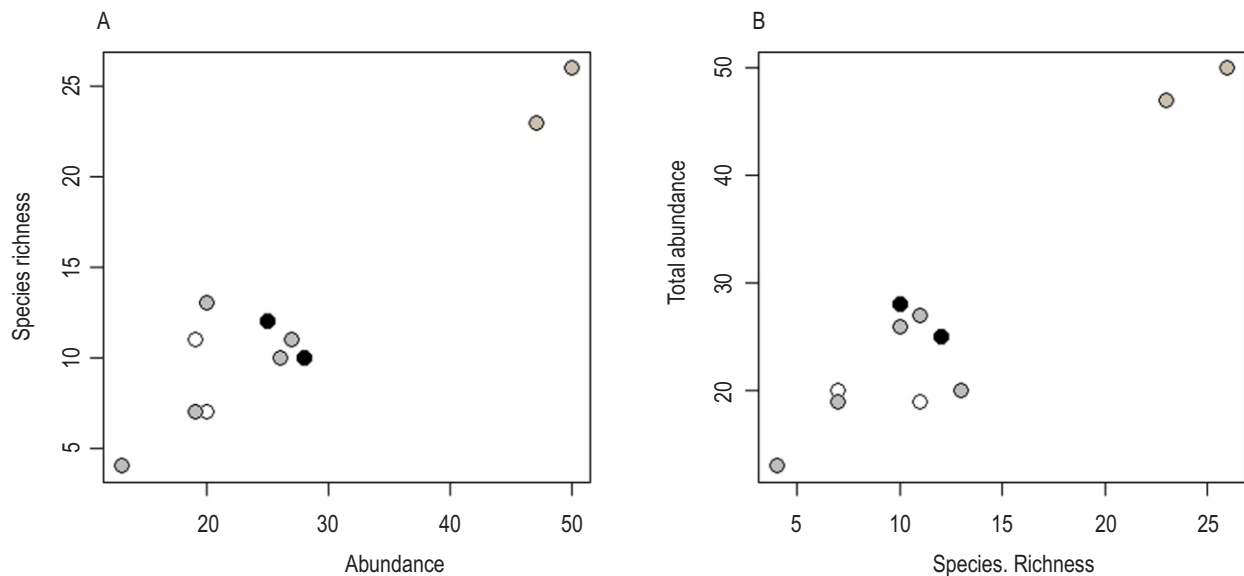
Fig. 4: Plot A shows a direct relation between species richness and abundance and opposite is also true as shown in plot B. Colors represent seasons as follows: Antique white for autumn, black for spring, grey for summer, and dark grey for winter. Such clear relationship in plots A and B appeared in all seasons. Table 4 explains the relationship in statistical terms.

Cyanophyceae and Chlorophyceae. Similar results were also observed by Turkoglu (2010). The phytoplankton community composition in this were study showed high abundance values, although species richness was low. This may be associated with the existence of some stressors that have restricted the species diversity to only lenient and permissive species to these particular environmental circumstances (Parnell, 2003). Diatoms were dominant in the subtidal waters of Umm Al-Namil Island followed by dinoflagellates (Table 5). This converse with the numerical dominance of diatoms in species number reported in other phytoplankton composition studies done at tropical latitudes (Rojas-Herrera *et al.*, 2012 b; Moreno-Díaz *et al.*, 2015; Varona-Cordero *et al.*, 2014; Rojas-Herrera *et al.*, 2012a,b). The groups of phytoplankton species are considered good relevance within marine environment water masses (Castillo *et al.*, 1993). During the course of survey, Dinophyceae sustained as fully evolved assemblage during winter.

Thirty-three species associated to Bacillariophyceae were analyzed. The highest abundance of Bacillariophyceae was detected in autumn and winter. The dominant species of Bacillariophyceae in most events were *Thalassiosira eccentrica, Navicula directa, Amphora sulcata, Bacillaria paxillifera, Bellerochea horologicalis, Cyclotella stylorum, Ditylum brightwellii, Diploneis weissflogii, Guinardia flaccida, Asterionellopsis glacialis* and *Biddulphia pulchella*. High quantity of nutrient in sewage water was primary disputation for the diatoms to grow successfully during this period. Varela and Prego (2003) also reported the dominance of diatoms in the Coruna Harbour (North West of Spain) to the nutrient loaded seawater.

Morais *et al.* (2003) stated that the increase in water temperature might have allowed phytoplankton to optimize its growth and productivity. Subsequently, Dinophyceae was also dominant in the phytoplankton community after diatoms. Amongst this, the most predominant species in the study site were *Ceratium tripos, Dinophysis caudata* and *Protoperidinium murrayi.* Cyanophyceae was the third prevalent group during the present investigation, constituting 7% of the total phytoplankton composition. Three species recorded in this research, were *Trichodesmium erythraeum, Lyngbya majuscula* and *Oscillatoria nigro viridis.* Chlorophyceae were infrequently documented and this result concurs with the reports of (2005) from the South China Sea. The presence of Chlorophyceae was restricted to few sampling events, the dominant species were *Pediastrum duplex* var. *clathratum, Cylindrotheca closterium, Dunaliella bioculata* and *Scenedesmus quadricauda.*

Diatoms *Navicula directa, Guinardia flaccida* and *Thalassiosira eccentrica* dominated during autumn (October-November 2016), and early dry season (Table 5). While dinoflagellate *Noctiluca scintillans* and Cyanophytes *Trichodesmium erythraeum* and *Oscillatoria nigroviridis* dominated only during the autumn season. Some studies indicate that changes in phytoplankton community structure can be conjoined with small changes in the sea surface temprature or nutrients concentrations in the water column (Langlois and Smith, 2001). The decrease in water temperature from November 2016 to March 2017 may have affected dinoflagellate abundance during this period as this microalgal group is highly sensitive to minor fluctuations in the temperature (Rojas-Herrera *et al.*, 2012;
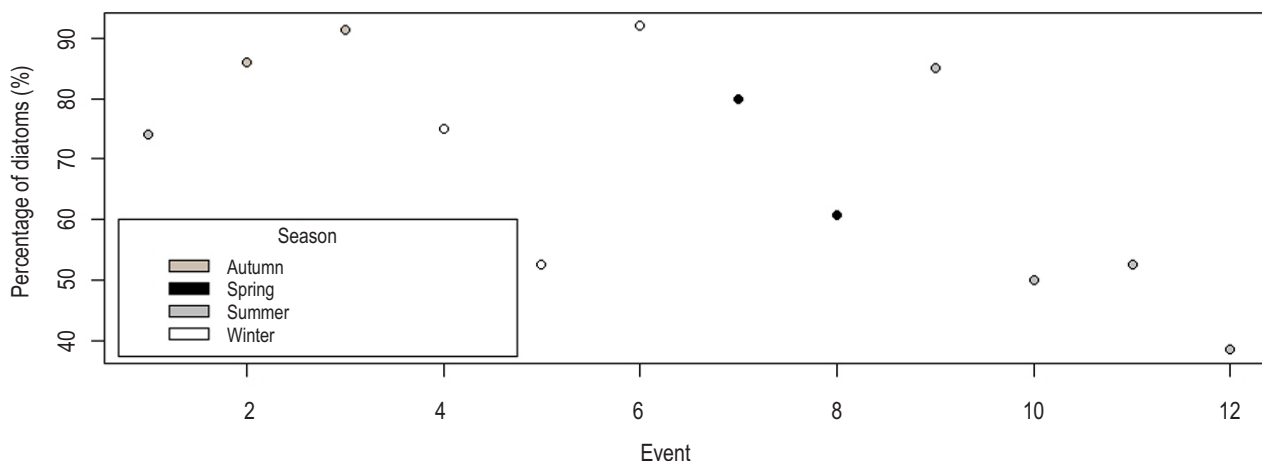
Fig. 5: Percentage of diatoms among other phytoplankton in the samples of each event (*i.e.,* month).The maximum percentage was 92% at event 6, while the lowest percentage (38.46%) was observed at event 12. Each color represents a season as shown on the legend.

Varona- Cordero *et al.*, 2014; Moreno-Díaz *et al.*, 2015). Diatoms, in disparity, are less sensitive to slight shifts in water temperature and responds more speedily to changing nutrient concentrations (Örnólfsdóttir *et al.,* 2004). Dominance of diatoms can be attributed to the presence of higher relative abundance of *Navicula directa, Guinardia flaccida, Thalassiosira eccentrica, Biddulphia pulchella, Bacillaria paxillifera* and *Diploneis weiflogii* (Table 5) during this study period. Among the six dinoflagellate species identified here, at least one (*Gymnodinium gracilentum*) has been reported to cause harmful algal blooms (HABs) in Kuwait waters (Al-Yamani *et al.,* 2000, 2012). In the present case, however, the majority of dinoflagellates like *Protoperidinium murrayi, Ceratium tripos, Noctiluca scintillans, Dinophysis caudata* and *Prorocentrum micans* found were not toxic (Table 5).

Species richness (46 species) and abundance values (13 to 50 ind $5l^{-1}$) recorded in the study area were within ranges previously stated in the other countries with similar climatic conditions (Rojas-Herrera *et al.*, 2012 b; Moreno-Díaz *et al.*, 2015; Rojas-Herrera *et al.*, 2012). The low values observed in this study commend that species composition alter among months in counter to fluctuation in environmental conditions over time. Inclusive, the results indicate that phytoplankton species richness and species abundance in Umm Al-Namil Island varied temporally in response to inconstancy in environmental conditions. Primary among these variations were higher nutrient concentrations and high discrepancy in water temperature in different seasons of the year contributed population growth in some dinoflagellate or diatom species at different times during the year. Furthermore, in another study in the same study area herein, the high species richness and abundance of phytoplankton observed seem to had reflected on the planktonic food web, in which nine larval fish families were recorded (Acropomatidae, Bregmacerotidae, Bythitidae, Clupeidae,

Engraulidae, Leioganthidae, Platycephalidae, Pseudochromidae and Sparidae) along with other zooplankton, mainly Copepoda, Mollusca larvae and Radiolaria (Ali *et al.*, 2020). In addition, it has been reported that diatoms are among the most vulnerable (mainly consumed) species in the Arabian Gulf food web (Ali, 2015). Diatoms are greater habituated to coastal environments, while dinoflagellates are better preferred to the oceanic environment (Castillo *et al.*, 1993; Rojas-Herrera *et al.*, 2012 b). The presence of diversity in the monthly cell profusion of these two substantial microalgal groups during the entire year (Fig. 3I, Table 5), propose that environmental circumstances in Umm Al-Namil Island's subtidal waters alter during the year in feedback to variations in numerous physico-chemical parameters. Alteration in the Kuwait Bay's water masses are supposedly echoed in the changing nature of its phytoplankton community. Different species prevail numerically during each month, signifying extensive variability in species composition in the course of time. Kruskal-Wallis test showed that the effect of temperature on phytoplankton abundance (Chi-Square = 145, df = 11, $p = 2.2 \times 10^{-16}$) salinity, (Chi-Square = 145, df = 11, $p = 2.2 \times 10^{-16}$) and DO (Chi-Square= 138.19, df = 9, $p = 2.2 \times 10^{-16}$) were significant (Table 2). Likewise, pH (Chi-Square= 134.6, df = 9, $p = 2.2 \times 10^{-16}$), various nutrients (Chi-Square= 60.713, df = 6, $p = 3.224 \times 10^{-11}$), nitrites (Chi-Square= 128.26, df = 8, $p = 2.2 \times 10^{-16}$), silicates (Chi-Square= 81.528, df = 10, $p = 2.518 \times 10^{-13}$) and phosphates (Chi-Square= 76.454, df = 4, $p = 9.814 \times 10^{-16}$) had significant effect on phytoplankton abundance. (Table 2). Season also had a significant effect on the abundance of phytoplankton species (Chi-Square = 109.16, df = 3, $p = 2.2 \times 10^{-16}$) (Table 2).

Similarly, a significant effect of season (Chi-Square = 99.435, df = 3, $p = 2.2 \times 10^{-16}$) and temperature was observed on the species richness (Chi-Square = 145, df = 11, $p = 2.2 \times 10^{-16}$) (Table 3). The effect of salinity and dissolved oxygen on species richness was also significant (Table 3). The effect of pH, nitrates,

silicate and phosphate on species richness was also significant (Table 3). The abundance showing statistically significant effect on the species richness in this study irrespective of season with a direct relationship (Chi-Square = 125.04, df = 8, *p* = 2.2 x 10^{-16}) (Table 4; Fig. 3A). Surprisingly, the other way was also true and species richness had a significant effect on the abundance (Chi-Square = 128.31, df = 7, *p* = 2.2 x 10^{-16}) (Table 4; Fig. 3B). The phytoplankton assemblages obtained from different temporal gradients over one-year study period in the Umm Al-Namil island's subtidal waters showed a total of 33 diatoms, 6 dinoflagellates, 3 cyanobacteria and 4 chlorophytes. Generally, diatoms have dominated all samples, while the other phytoplankton groups were minor at almost all the events (Table 4; Fig. 5). The highest diatom percentage (over 70%) was observed at event 6 in winter (92%), event 3 in autumn (91.49%), event 2 in autumn (86%), event 9 in summer (85%), event 7 in spring (80%), event 4 in winter (75%), and event 1 in summer (74.07%, Fig. 5). Percentage of diatoms was 60.71% at event 8 in spring (Fig. 5). Percentage of diatoms ranged between 50 to 52.63% during events 10 (summer), 5 (winter) and 11 (summer), respectively, as the percentage at the latter 2 events are same (Fig. 4).The lowest percentage of diatoms was observed at event 12 in summer (38.46%) (Fig. 4) that also coincided with lowest abundance and lowest species richness as explained above (Fig. 2J). Other observed phytoplankton groups were dinoflagellates, cyanobacteria and chlorophytes (Table 5). Almost similar observations were reported by from (Chakraborty *et al.,* (2015) from Andaman Sea and Indian Ocean.

The most encountered diatoms *Thalassiosira eccentrica*, *Navicula directa* and *Amphora sulcata*; were present at 6 sampling events at almost all the seasons despite their level of abundance. The abundance of *Thalassiosira eccentrica* was 3,5,5,3,1,3 (ind 5l^{-1}) at events 2,3,6,9,10 and 11. The abundance of *Navicula directa* was 2,3,2,2,4,2 (ind 5l^{-1}) at events 1,2,3,5,6 and 7. The abundance of *Amphora sulcata* was 2,1,2,2,2,1 (ind 5l^{-1}) at events 1,2,6,7,8 and 9, respectively. Diatoms *Bacillaria paxillifera*, *Bellerochea horologicalis*, *Cyclotella stylorum* and *Ditylum brightwellii* were encountered at 5 sampling events at almost all seasons despite the level of abundance. The abundance of *Bacillaria paxillifera* was 3,2,4,1,3 (ind 5l^{-1}) at events 1,3,7,9 and 10. The abundance of *Bellerochea horologicalis* was 2,2,2,2,3 (ind 5l^{-1}) at events 2,3,4,5 and 6, (Table 5). The abundance of *Cyclotella stylorum* was 2,2,1,1,2 (ind 5l^{-1}) at events 1,3,5,10, and 11, (Table 5). The abundance *Ditylum brightwellii* was 3,1,1,1,2 (ind 5l^{-1}), at events 1,2,3,5 and 7, respectively (Table 5).

The diatoms *Diploneis weissflogii*, *Guinardia flaccida*, *Asterionellopsis glacialis* and *Biddulphia pulchella* were encountered at 4 sampling events at almost all seasons despite the level of abundance. The abundance of *Diploneis weissflogii* was 3,4,3,5 (ind 5l^{-1}) at events 9,10,11 and 12. The abundance of *Guinardia flaccid* was 3,3,5,1 (ind 5l^{-1}) at events 2,3,4 and 6. The abundance of *Asterionellopsis glacialis* was 2,3,4,2 (ind 5l^{-1}) at events 8,9,10 and 11. The abundance of *Biddulphia pulchella* was 3,3,1,3 (ind 5l^{-1}) at events 1,2,6 and 7. Diatoms *Chaetoceros affinis*, *Thalassionema nitzschioides* and *Licmophora abbreviata*

were encountered at 3 events, irrespective of season (Table 5). The abundance of *Chaetoceros affinis* was 1,1,1 (ind 5l^{-1}) at events 1,7, and 9. The abundance of *Thalassionema nitzschioides* was 6,1,2 (ind 5l^{-1}) at events 4,5, and 8, (Table 5). The abundance of *Licmophora abbreviata* was 2,1,4 (ind 5l^{-1}) at events 2,3, and 8, respectively. The remaining diatoms appeared in only 2 events irrespective of season (*Bacteriastrum delicatulum, Nitzchia longissimi, Coscinodiscus centralis, Lauderia annulata, Thalassiothrix longissima, Leptocylindrus danicus, Odontella mobiliensis, Pleurosigma elongatum, Triceratium reticulum, Pseudonitzschia delicatissima, Corethron criophilum,* and *Hemiaulus sinensis*), or even one event (*Melosira moniliformis, Gyrosigma diminutum, Fragilaria martyi, Hemidiscus cuneiformis, Planktoniella sol* and *Amphipro raplicata*) (Table 5).

Dinoflagellates were the second most abundant group of phytoplankton in this study. Only 6 species *viz., Ceratium tripos, Dinophysis caudata, Protoperidinium murrayi, Noctiluca scintillans, Prorocentrum micans* and *Gymnodinium gracilentum* were encountered. The most commonly encountered dinoflagellate was *Ceratium tripos*, which was observed at eight events irrespective of the seasons. The abundance of *Ceratium tripos* was 1, 1,3,2,2,2,2,1 (ind 5l^{-1}), at events 1,2,3,5,7,8,9 and 10. Both *Protoperidinium murrayi* and *Dinophysis caudata* were observed only at four events despite seasons. The abundance of *Dinophysis caudata* was 3,1,2,3 (ind 5l^{-1}) at events 4, 7, 8 and 12, while the abundance of *Protoperidinium murrayi* was 1,2,3,3 (ind 5l^{-1}) at events 4, 5, 6, and 11. The abundance of *Prorocentrum micans* was 1,1,2 (ind 5l^{-1}) at events 7,9 and 10, respectively. The abundance *Noctiluca scintillans* was 2,3 (ind 5l^{-1}) at events 1 and 2. The toxic dinoflagellate, *Gymnodinium gracilentum* was encountered only at event 5 with the abundance value of 2 (ind 5l^{-1}) (Table 5).

Chlorophytes were represented in this study by the presence of *Pediastrum duplex var. clathratum, Cylindrotheca closterium, Dunaliella bioculata* and *Scenedesmus quadricauda*. The abundance of *Pediastrum duplex* var. *clathratum* was 2,3,1 (ind 5l^{-1}), at events 2,3,9. The abundance of *Cylindrotheca closterium* was 1,1,2 (ind 5l^{-1}), at events 1,2, and 3.The abundance of *Dunaliella bioculata* was 1,1,1 (ind 5l^{-1}), at events 10,11 and 12. The abundance of *Scenedesmus quadricauda* was 2,1 (ind 5l^{-1}), at events 2 and 12. Cyanobacteria were represented in this study by *Trichodesmium erythraeum, Lyngbya majuscula* and *Oscillatoria nigro viridis*. The most encountered cyanobacteria was *Trichodesmium erythraeum* at events 1 to 8 covering all seasons, with the abundance values of 1,1,2,2,3,2,1, and 7 (ind 5l^{-1}). The abundance of *Lyngbya majuscula* was 1,2,4,5,2 (ind 5l^{-1}), at events 4,9,10,11 and 12. The abundance of *Oscillatoria nigro viridis* was 2, 2, 2, 5 (ind 5l^{-1}), at events 2,3,9 and 10, respectively (Table 5).

The correlation between diversity, species richness, abundance, and their dependence on resource possibility and disproportion have been investigated from divergent standpoint, including the Resource-Ratio Theory (RRT, Tilman 1982),

Species-Energy Theory (SET, Wright 1983) and the biodiversity ecosystem functioning (BEF) criterion (Naeem *et al.,* 1994; Gross and Cardinale, 2007; Hillebrand and Matthiessen, 2009). It is easy to understand that all these avenues explain essential, but not adequate, range to demonstrate the abundance–diversity relationships in disposition. Cardinale *et al.* (2009) proposed that recognized diversity richness–abundance relationships are built by the interaction of four specific, non-compatible variables: quantity of confine resources, resource inequality, and species richness, and tested this access with practical, substantial phytoplankton data (Lehtinen *et al.,* 2017). They highlighted that experimentally controlled research, with controls of resource proportion, their ratios, and species richness would be probable to check the combined influence of the factors on biomass and abundance. The present study revealed that abundance had a significant effect on the species richness and diversity has been shown also to hike the resistance of plankton communities (Ptacnik *et al.,* 2008). The results of this study alone has narrow descriptive strength for forecasting of winner species in planktonic windows of possibility, and for the outcomes of events of resource domination, in the paucity of quantitative data on their ecological characteristics. These features comprise explanation of competitive might within a set of environmental context, but also the "consumer standpoint (Litchman and Klausmeier 2008; Vallina *et al.,* 2014). Inconsistent to many earlier investigations on biodiversity-ecosystem active interrelation, we found a highly symbolic inverse relationship between abundance and species richness. This indicates that species-rich natural phytoplankton communities form the basis for opportunistic species to temporarily monopolize resources and create blooms.

Kuwait's presumably unspoilt environment is intimidated by possible naturally associated influences that development may have on this ecological region. Among these hazards are loss of vital habitat to development, contamination due to poisonous chemicals associated with oil exploration, invasive species from ballast waters and eutrophication (Ibrahim and El Samra, 1987; Al-Muzaini and Jacob, 1996; Subba-Rao *et al.,* 1999; ROPME, 1999; Nour El-Din and Al-Khayat, 2005; Sheppard *et al.,* 2010). Moreover, "brine" released from desalination plants with salinities >75 psu has increase salinity in already hypersaline water bodies, especially during summer due to high evaporation leading to higher salinity as seen during events 9-12 in this study (Abdul Azis *et al.,* 2003; Lattemann and Hopner, 2008; Sheppard *et al.,* 2010). The temporal variations in abundance and species richness of the phytoplankton community show that physico-chemical factors and seasons play a major role in the functioning of this evidently emphatic ecosystem.

Further detailed studies are needed in other subtidal waters of North-western Arabian Gulf, mainly in the north and south of Kuwait, considering phytoplankton ecology and species composition including benthic diatoms and the effect of pollution. Also, increasing the study sites in future; extending to different areas north and south is needed in order to compare the diversity

and species composition in the study area. Divergence in the phytoplankton groups reflects the seasonal fluctuations and impact of water quality. Presence of potentially harmful algal species even in low counts, make the region susceptible to harsh effects due to flourishing of these species during favorable conditions. Continuous monitoring of this area is essential to follow probable bloom of these species, to predict negative effects deriving from developing land activities, anthropogenic inputs and climate change.

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