التغيرات الفصلية وتنوع الهائمات النباتية في بحيرة شرم ينبع، البحر الأحمر، المملكة العربية السعودية

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المستخلص. مدينة ينبع واحدة من أهم المناطق الصناعية والسياحية على الجانب الشرقي من ساحل البحر الأحمر، وتشهد توسعاً في بناء المرافق والصناعات الحديثة، حيث يوجد ميناء صناعي لنقل وتصدير المنتجات البترولية والصناعات المختلفة، ويمكن أن تؤثر هذه الأنشطة والتوسع على البيئة الساحلية، والذي يمكن أن يكون مؤشراً على حالة الهائمات النباتية. لذلك، أجريت دراسة موسمية للهائمات النباتية والعوامل البيئية، بهدف معرفة نشاط وحيوية الهائمات النباتية وعلاقتها بالعوامل الفيزيائية والكيميائية. تمت الدراسة في ٦ محطات: ٥ محطات داخل البحيرة ومحطة عند المدخل بين البحيرة والبحر الأحمر. تراوحت درجة حرارة الماء من ٢٢,٠٠°م إلى ٣٣,٣٠°م (بمتوسط ٢٦,٩٠°م) وكان تركيز الكلوروفيل من ٠,٠٧ إلى ٢,٢٠ ملجرام/م^٣ (بمتوسط ٠,٣٩ ملجرام/م^٣). وتم التعرف على ١٦٨ نوعاً من الهائمات النباتية من بينها ٩٤ تنتمي إلى الهائمات العصوية، و ٦٩ من السوطيات، و ٣ من الخضراء المزرقّة، و ١ من الطحالب الخضراء، و ١ من *Mediophyceae*. اختلفت وفرة الهائمات النباتية من ٢,٣٤×١٠^٣ إلى ١٢,٠٧×١٠^٣ خلية/لتر، والأعلى والأدنى كانت في الربيع والشتاء، على التوالي. وقد ساهمت الهائمات العصوية بـ (٥٤,٩٥٪)، تلتها السوطيات (٤٠,٠٧٪)، ثم الطحالب الخضراء المزرقّة (٣,٧٩٪) والطحالب الخضراء (٠,٦٠٪) و *Mediophyceae* (٠,٦٠٪) من مجموع الهائمات النباتية. بين العصويات، الريشيات والدائرية كانت ٣٢,٣٤٪ و ٢٢,٢٨٪، على التوالي. وأظهرت العوالق النباتية علاقة إيجابية مع الكلوروفيل في الربيع والصيف والخريف ($r = 0.64$ ، و $r = 0.59$ ، و $r = 0.66$)، على التوالي.

الكلمات المفتاحية: الهائمات النباتية، العوامل البيئية، تكوين المجتمع، الديناميكية، التنوع.

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5. Conclusions

Low abundance cell of phytoplankton at Sharm Yanbu lagoon in comparison with other coastal area of different oceans or sea indicates the oligotrophic status of water body. Increased abundance of dinoflagellates is the symptom of red tide in near future, thus, it is very important to find out reason of increasing nutrients in this lagoon. Nutrients of $\text{NH}_3\text{-N}$, $\text{NO}_3\text{-N}$ and $\text{SiO}_3\text{-Si}$ were the most important factors to influence phytoplankton abundance in this lagoon. However, the most abundant group was Bacillariophyceae followed by Dinophyceae as taxonomic group of phytoplankton. To keep the lagoon coast suitable for the tourists monitoring work should carry on year after year.

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Khairy (2014) who found 138 and 128 species, respectively, and lower than that of the finding of Devassy *et al.* (2017) who recorded 311 species.

Phytoplankton cell abundance and different environmental factors showed significant positive correlation in different seasons. Phytoplankton cell abundance showed significantly negative correlation with temperature in summer, autumn and winter which were $r = -0.51$, -0.91 and -0.52 , respectively. Cell abundance showed significantly positive correlation with $\text{NO}_3\text{-N}$ in summer which was $r = 0.56$ and a non-significant positive correlation with cell abundance in spring which was $r = 0.29$, while it showed significantly negative correlation with $\text{NH}_4\text{-N}$ and $\text{PO}_4\text{-P}$ in summer and winter which were $r = -0.54$ and -0.63 , respectively.

During the study, average phytoplankton cell abundance was higher in spring and summer than that of the cell abundance of autumn and winter. This result is similar with the finding of Nassar and Mohamed (2003) who reported that autumn was the highest productive season of phytoplankton production at Suez bay (Red Sea), EGYPT. In this study area, the correlation values of $\text{NO}_3\text{-N}$, and temperature showed significantly positive relation with phytoplankton abundance in spring. The nutrients are the important chemical factors for controlling phytoplankton community composition and dynamics (Lund, 1949; Talling, 1955; Grovrt, 1989 and Reolke *et al.* 199). The laboratory experiments and field studies have shown that episodic nutrients flushing and loading enhance phytoplankton species diversity (Padisak, 1993; Hambright and Zohary, 2000 and Lovejoy *et al.* 2002). Therefore, it can be assumed that nitrogenous nutrients and temperature might have created suitable condition for higher growth of phytoplankton in spring and summer. Bacillariophyceae

showed higher percentage contribution in summer and spring. Morais *et al.* (2003) found that the increase of water temperature allowed phytoplankton especially diatoms to optimize its growth and productivity. Affan and Lee (2004) also found that diatoms abundance was more at early summer at Jeju Coastal area, East China Sea. Our finding of diatoms abundance is also agreed with temperature phenomena. Therefore, it can be assumed that high temperature and nutrients have created a favorable condition for growing more diatoms in summer at the lagoon. *Pseudo-nitzschia seriata* was dominating species among phytoplankton in winter though most of the diatoms were dominated in spring and summer. In winter, especially, the concentration of $\text{NH}_4\text{-N}$, $\text{PO}_4\text{-P}$ and $\text{SiO}_3\text{-S}$ were comparatively higher than that of other seasons. Martin-Jézéquel (2015) studied the effects of organic and inorganic nitrogen on the growth and production of domoic acid by *Pseudo-nitzschia* sp. and found that the cell abundance was more when ammonium concentration was high. Thus, it can be said that comparatively higher concentrations of $\text{NH}_4\text{-N}$, $\text{PO}_4\text{-P}$ and $\text{SiO}_3\text{-S}$ might have created suitable conditions for the higher proliferation of *Pseudo-nitzschia* sp., at the lagoon in winter. Among, Dinophyceae, the most dominant in spring and autumn, and common species was *Prorocentrum mincans* throughout the study. It is well known that autumn bloom in ocean generally governed by Dinophyceae. Affan *et al.* (2007) also found a high dense autumn bloom of phytoplankton caused by dinoflagellates. They also reported that *Prorocentrum triestinum* was the most abundant species which contributed 30.1% and 15.3% of total phytoplankton abundance. Therefore, it can be said that this lagoon might have created favorable condition during spring and autumn due to moderate temperature and with $\text{NO}_3\text{-N}$ for higher growth of dinoflagellates.

(NO₃-N), phosphate (PO₄-P) and silicate (SiO₃-S) as well as diluted CO₂ thus decreasing of those make the pH high.

The concentrations of nutrients have a clear and significant influence on the occurrence and abundance of phytoplankton. The Red Sea water is in general low in the major nutrients such as nitrate, phosphate, ammonia and silicates due to lack of any river inflow to the sea. In the Red Sea, the nutrients enrichment occur by the inflow of rich intermediate water from the Gulf of Aden during late summer and the nutrients concentrations can increase by up to 25% the Red Sea, and can increase the primary production up to 300% (Thiel, 1990). Additionally, during the summer month southwest monsoon season (May to September) and in winter north to northwest winds blow along the whole axis of the Red Sea. The Red Sea surface waters pile up from December to February along the African coast and some upwelling occurs along the Arabian coast (Marcos, 1970), and reversal of summer condition because of the south-southeast winds only affect the southern half of the Red Sea. However, the sand storms from those winds occur which may input nutrients to the Red Sea.

During the study, the highest concentration of SiO₃-Si was found at St.4. in spring, which was much lower than that of the concentration of SiO₃-Si of the Red Sea. The concentration of silicate ranged between 0.1 to 0.8 µg L⁻¹, and the concentration generally increases with depth and reaches a maximum of about 25 µg L⁻¹ in the southern Red Sea at a depth between 80-200m (Rushdi, 1996). Here, the occurrence of low concentration of SiO₃-Si in comparison with the concentration of the Red Sea indicates that the Red Sea water mass has less influence to the lagoon. NH₃-N showed negative correlation with temperature in the summer ($r = -0.24$). This finding is

similar with the results of Affan *et al.* (2007) who reported that NH₄+N showed negative correlation with temperature in summer at West coast off Jeju Island, Korea. However, similarly, other nutrients also did not show significant correlation with temperature.

4.3 Dynamics of Chlorophyll *a*

Chlorophyll *a* is one of most important indicator of primary productivity. Chlorophyll *a* concentration increases with the increasing of phytoplankton cell abundance. The highest concentration of Chlorophyll *a* was 2.20 µg L⁻¹ at St.4. in spring with an average of 0.39 µg L⁻¹ in the study area. Chlorophyll *a* showed significantly positive correlation with phytoplankton cell abundance in spring, summer and autumn which was $r = 0.64$, $r = 0.59$ and $r = 0.66$, respectively. Al-Harbi and Khomayis (2005) found the variation of the chlorophyll *a* levels from 0.015 mg.m⁻³ and 0.158 mg.m⁻³ at Obhur creek of the Red Sea where the high value of chlorophyll *a* was in winter and autumn. Temperature and nutrients might have played very important role to create a suitable or optimum condition for proliferation and growth of the phytoplankton in those seasons. Thus, it can be said that moderate temperature and the nutrients might have created favorable condition for the growth phytoplankton which ultimately increase the chlorophyll *a* concentration in spring of the lagoon.

4.4 Phytoplankton Dynamics in Relation with Environmental Factors

During the study, a total 168 species of phytoplankton was to represent community, and the highest dominant group was Bacillariophyceae followed by Dinophyceae. Our finding of the number of species of phytoplankton occurrence was a bit higher than that of the phytoplankton species found in the proper Red Sea reported by Abbas *et al.* (2018), Kürten *et al.* (2015) and Nassar &

Autumn	ST.1	ST.2	ST.3	ST.4	ST.5	ST.6
Dinophyceae						
<i>Ceratium furca</i> Ehrenberg			16.62	16.67		
<i>Dinophysis acuminata</i> Lachmann	21.80	17.11	18.40			
<i>Prorocentrum micans</i> Ehrenberg	17.44	15.53	23.15	15.49		
<i>Protoperidinium quinquecorne</i> Abé						10.13
Cyanophyceae						
<i>Oscillatoria</i> sp.,					11.67	22.48
Winter	ST.1	ST.2	ST.3	ST.4	ST.5	ST.6
Bacillariophyceae Diatoms						
Centric						
<i>Guinardia striata</i>	10.10		13.40	14.29		
pennate						
<i>Pseudo-nitzschia seriata</i>			12.20	14.05		
Dinophyceae						
<i>Ceratium furca</i> Ehrenberg	12.02	22.25				
<i>C. fusus</i> Ehrenberg		12.68				
<i>Dinophysis acuminata</i> Lachmann	16.59	12.11		13.57	14.95	15.69
<i>Prorocentrum micans</i> Ehrenberg	18.75		21.29	19.52	21.18	23.72

4. Discussion

In any ecosystem, there are interactions between the biotic and a biotic factor. In aquatic ecosystem, there is an interaction between phytoplankton and environmental factors such as physical (temperature, light and wave etc.) and chemical (nutrients). These interactions have direct or indirect influence on temporal dynamics of phytoplankton as well as for qualitative and quantitative changes in phytoplankton community structure, biomass production and dynamic, e.g. increases or decreases of size of the population (Welch, 1952). Those abiotic factor also vary in different seasons and in different regions.

4.1 Dynamics of Temperature

Temperature variation showed distinct seasonality characterized by maximum in summer, followed by autumn, spring and winter. Similarly, Edwards (1987) found that temperature varied from 21.60 to 32.30°C with an average of 28.05°C in the Red Sea. Morcos (1970) and Abdullah (1985) reported that the sea surface temperature of the Red Sea was below 25°C in winter (December-February) and high was 31°C in summer (June-

September). In this study, the highest temperature was found 33.30°C in summer (August), which is a bit higher than the reported results of Al-Barakati (2012) who found the maximum 28.66°C of temperature during his study. In winter the winds blow from both ends of the Red Sea towards the region of maximum temperature, while in summer north-westerly winds dominate the whole area. Thus, it can be said that wind direction and current are the main factors for making seasonal changes in temperature.

4.2 Dynamics of pH and Nutrients

pH is an important factor for the growth and proliferation of aquatic organisms. It is also called the productivity index of a water body. The present study revealed that the pH values of the investigated sites were neutral to alkaline. The minimum pH was recorded at St.44 in winter. pH and temperature showed significantly positive correlation ($r = 0.66$) in spring. In summer, the non-significant negative correlation was between temperature and pH which was $r = -0.30$. Growth of phytoplankton is one of the indication of increasing pH or vise-versa. The fact is that when phytoplankton grow, it uptakes nitrate

Species occurrence frequency				
	Spring	Summer	Autumn	Winter
<i>Protoperdinium</i> sp.,	H	H	F	
<i>P. cassum</i> Balech				R
<i>P. cerasus</i> Balech		R		
<i>P. claudicans</i> Paulsen	X	X		
<i>P. depressum</i> Bailey			R	X
<i>P. divergens</i> Ehrenberg	R	H	H	H
<i>P. ovatum</i> Pouchet		X	H	X
<i>P. oviforme</i> Balech		X		
<i>P. ovum</i> Balech				C
<i>P. pallidum</i> Balech		X		
<i>P. pentagonum</i> Gran	X			
<i>P. quarnerense</i> Schröder		X		
<i>P. quinquecorne</i> Abé			H	H
<i>P. steinii</i> Balech	H	F		
<i>Pseudophalacroma nasutum</i> Jorgensen			X	
<i>Pyrophacus</i> sp.,			X	
<i>Scrippsiella trochoidea</i> Stein	H	H	F	F
Chlorophyta				
<i>Dunaliella salina</i> Teodo.	R			X
Cyanophyceae				
<i>Oscillatoria</i> sp.,	F	H	H	H
<i>Spirulina</i> sp.,		X		X
<i>Trichodesmium</i> sp.,	C	C	C	C
Mediophyceae				
<i>Climacosphenia moniligera</i> Ehrenberg		X	X	

Legend of occurrence frequency: Sporadically (X = 1-20%), Rarely (R = 21-40%), Commonly (C = 41-60%), Frequently (F = 61-80%) and High frequently (H = 81-100%)

Table 3. List of phytoplankton species predominance (above 10%) at Sharm Yanbu lagoon of Saudi Arabia from spring to winter, 2016-2017.

Spring	ST.1	ST.2	ST.3	ST.4	ST.5	ST.6
Bacillariophyceae Diatoms						
Pennate						
<i>Cylindrotheca closterium</i> Ehrenberg			15.89			
Dinophyceae						
<i>Dinophysis acuminata</i> Lachmann	11.03	11.03			14.86	15.82
<i>Prorocentrum lima</i> Ehrenberg	11.72					
<i>P. micans</i> Ehrenberg		12.46	11.26	11.63	10.86	12.03
<i>Scrippsiella trochoidea</i> Stein						10.13
Cyanophyceae						
<i>Oscillatoria</i> sp.,					15.43	
Summer	ST.1	ST.2	ST.3	ST.4	ST.5	ST.6
Bacillariophyceae Diatoms						
Pennate						
<i>Licmophora flabellata</i> Greville			11.22			
Dinophyceae						
<i>Ceratium furca</i> Ehrenberg					10.09	
<i>Diplopsalis lenticula</i> Bergh						10.65
<i>Prorocentrum lima</i> Ehrenberg			10.89			
<i>P. micans</i> Ehrenberg			14.19	12.85		10.27
Cyanophyceae						
<i>Oscillatoria</i> sp.,		10.69		15.26		13.31

Species occurrence frequency				
	Spring	Summer	Autumn	Winter
<i>Synedra</i> sp.,	C	X	R	
<i>S. gaillonii</i> Bory		X		
<i>Thalassionema frauenfeldii</i> Grunow				X
<i>Trachyneis aspera</i> Ehrenberg			X	R
Dinophyceae				
<i>Alexandrium</i> sp.,	R	F	X	
<i>A. tamarense</i> Lebour	X	R	X	X
<i>Amphidinium</i> sp.,	X	X		
<i>A. operculatum</i> Lachmann				X
<i>Ceratium</i> sp.,		X	X	
<i>C. kofoidii</i> Jørgensen			F	C
<i>C. arietinum</i> Cleve			C	
<i>C. breve</i> Schröder			X	
<i>C. candelabrum</i> Ehrenberg	X			R
<i>C. declinatum</i> Karsten		X	X	
<i>C. egyptiacum</i> Halim			X	X
<i>C. extensum</i> Cleve			F	X
<i>C. furca</i> Ehrenberg	H	H	H	H
<i>C. fusus</i> Ehrenberg	R	F	H	H
<i>C. horiddum</i> Cleve	H		R	
<i>C. lineatum</i> Ehrenberg	X	X		
<i>C. longsturm</i>			X	
<i>C. macroceros</i> Ehrenberg	X	H	H	
<i>C. pentagonum</i> Gourret	C	R		
<i>C. teres</i> Kofoid			F	H
<i>C. trichoceros</i> Ehrenberg			H	C
<i>C. tripos</i> Müller	X	R	R	R
<i>Dictyocha fibula</i> Ehrenberg				H
<i>Dinophysis</i> sp.,	R			
<i>D. acuminata</i> Lachmann	H	H	H	H
<i>D. caudata</i> Saville-Kent	R	C	H	H
<i>Diplopsalis lenticula</i> Bergh		F	H	F
<i>Gonyaulax</i> sp.,	F	F	R	X
<i>G. digitalis</i> Pouchet			H	H
<i>G. fusiformis</i> Graham		X	X	
<i>G. grindleyi</i> Reinecke	X	X	R	
<i>G. polygramma</i> Pouchet		X		
<i>G. spinifera</i> Lachmann	F	H	F	H
<i>G. verior</i> Sournia		R		
<i>Gymnodinium</i> sp.,	R	F		
<i>G. sanguineum</i> Hirasaka	F	H	H	H
<i>Gyrodinium</i> sp.,		R		
<i>G. spirale</i> Bergh		R	F	R
<i>Oxytoxum milneri</i> Murray		X	X	H
<i>Oxytoxum sceptrum</i> Stein	X		X	R
<i>Oxytoxum scolopax</i> Stein			X	R
<i>Phalacroma rotundatum</i> Lachmann	X	F	H	X
<i>Podolampas palmipes</i> Stein	X	R	H	C
<i>Polykrikos schwartzii</i> Bütschli	X			
<i>Prorocentrum balticum</i> Lohmann		X		
<i>P. compressum</i> Balech			C	
<i>P. gracile</i> Schüt.	H	C	H	H
<i>P. lima</i> Ehren.	H	H	H	H
<i>P. micans</i> Ehrenberg	H	H	H	H
<i>Protoceratium reticulatum</i> Lachmann		C		C
<i>Protoperidinium brevipes</i> Balech	C	F		X
<i>P. brochii</i> Kofoid	C	F		

Species occurrence frequency				
	Spring	Summer	Autumn	Winter
<i>R. stolterforthii</i> Peragallo		H		
<i>Stephanopyxis palmeriana</i> Greville				X
<i>Surirella</i> sp.,				X
<i>S. brebissonii</i> Krammer			X	
<i>S. fastuosa</i> Ehrenberg		X	X	X
Pennate Diatoms				
<i>Amphiprora</i> sp.,			R	
<i>A. alata</i> Ehrenberg		X		
<i>A. paludosa</i> Smith	X	X		
<i>Amphora</i> sp.,	C	R	R	X
<i>A. decussata</i> Grunow			X	
<i>A. lineata</i> Gregory			X	
<i>A. spectabilis</i> Gregory			R	
<i>Bacillaria paxillifera</i> Müller		X	X	X
<i>Cocconeis</i> sp.,				X
<i>C. scutellum</i> Ehrenberg	R	H	C	X
<i>Cylindrotheca closterium</i> Ehrenberg	H	R	F	C
<i>Diploneis</i> sp.,	X		R	X
<i>D. aff. gemmatula</i>			X	
<i>D. crabo</i> Ehrenberg	X	H	C	C
<i>D. splenda</i> Gregory	R			
<i>D. suborbicularis</i> Cleve			X	
<i>Ditylum brightwellii</i> Grunow			X	
<i>Donkinia recta</i> Donkin			F	R
<i>Gyrosigma</i> sp.,		X		
<i>Hantzschia</i> sp.,			X	
<i>H. virgata</i> Roper				X
<i>Licmophora</i> sp.,	X	F	F	
<i>L. dalmatica</i> Kützing		X		R
<i>L. flabellata</i> Greville	R	R	R	R
<i>L. paradoxa</i> Lyngbye		X		
<i>Mastogloia</i> sp.,		X		
<i>M. decussata</i> Grunow		C		X
<i>Navicula</i> sp.,	H	C	R	
<i>N. directa</i> Cleve		X		
<i>N. distans</i> Smith		X		
<i>N. elegans</i> Smith		R		
<i>N. lyra</i> Ehrenberg	X		X	R
<i>N. lyroides</i> Hendey	R	X	R	X
<i>N. menaiana</i> Hendey				X
<i>Nitzschia</i> sp.,	X			
<i>N. longissima</i> Smith	R		C	R
<i>N. panduriformis</i> Gregory			X	
<i>N. sigma</i> Grunow	X	X	R	
<i>Pinnularia rectangulata</i> Gregory	X			X
<i>P. trevelyana</i> Donkin			X	
<i>Plagiotropis lepidoptera</i> Gregory		X	F	C
<i>Pleurosigma</i> sp.,	X	R	X	
<i>P. delicatulum</i> Smith		X		
<i>P. directum</i>	X			
<i>P. elongatum</i> Smith				X
<i>P. formosum</i> Smith	X		X	C
<i>P. longum</i> Cleve		C		
<i>Pseudo-nitzschia pungens</i> Hasle			X	
<i>Pseudo-nitzschia seriata</i> Cleve		R	R	H
<i>Stauroneis membranacea</i> Cleve		R	X	
<i>Stenopterobia</i> sp.,	X			

Table 1. Seasonal dynamics of NO₃-N, NO₂-N, NH₄-N, PO₄-P and SiO₂-S of 6 stations (St.s) at Sharm Yanbu lagoon of Saudi Arabia from spring to winter, 2016-2017.

St.s	NO ₃ -N				NO ₂ -N				NH ₄ -N				PO ₄ -P				SiO ₂ -S			
	Spr	Sum	Aut	Win	Spr	Sum	Aut	Win	Spr	Sum	Aut	Win	Spr	Sum	Aut	Win	Spr	Sum	Aut	Win
St.1	0.37	0.24	1.12	0.11	0.85	0.24	0.34	0.12	0.17	0.25	0.18	0.21	0.40	0.24	0.23	0.30	2.74	0.80	0.69	1.38
St.2	0.40	0.72	1.01	0.29	0.90	0.30	0.42	0.18	0.15	0.06	2.02	0.19	0.86	0.28	0.22	0.21	2.73	0.50	0.73	1.01
St.3	0.83	1.27	0.44	0.14	0.68	0.24	0.34	0.12	0.11	0.21	0.18	0.29	1.51	0.47	0.32	0.26	2.41	1.21	0.55	0.97
St.4	0.71	0.83	1.28	0.45	0.59	0.42	2.21	0.32	0.08	0.19	0.15	1.65	0.94	0.91	0.48	0.83	6.28	2.31	2.31	1.93
St.5	0.37	0.55	0.32	0.20	0.66	0.26	0.36	0.14	0.09	0.33	0.26	0.22	1.38	0.21	0.32	0.27	1.28	0.85	0.21	1.01
St.6	0.39	0.63	0.28	0.23	1.51	0.22	0.31	0.09	0.79	0.44	0.51	0.23	0.39	0.22	0.19	0.36	1.68	0.70	0.69	0.50

***Winter, Win; Spring, Spr; Summer, Sum; Autumn, Aut.

Table 2. List and occurrence frequency of microalgae taxa at Sharm Yanbu lagoon of Saudi Arabia from spring to winter, 2016-2017.

	Species occurrence frequency			
	Spring	Summer	Autumn	Winter
Bacillariophyceae				
Centric Diatoms				
<i>Bacteriastrum delicatulum</i> Cleve		X		H
<i>B.varians</i> Lauder		X		
<i>Chaetoceros</i> sp.,	F	H	H	R
<i>C. affinis</i> Lauder				R
<i>C. atlanticus</i> Cleve	R		F	R
<i>C. compressus</i> Lauder	X	R	X	
<i>C. curvisetum</i> Cleve		X	X	C
<i>C. debilis</i> Cleve	X	R		
<i>C. decipiens</i> Cleve		X		X
<i>C. didymus</i> Ehrenberg	X			
<i>C. lorenzianus</i> Grunow	C			H
<i>C. peruvianus</i> Brightwell	X	X		H
<i>C. pseudocrinitus</i> Ostenfeld	X			C
<i>Corethron criophilum</i> Castracane				X
<i>Coscinodiscus</i> sp.,		X	R	X
<i>C. excentricus</i> Ehrenberg	X	X	H	H
<i>C. marginatus</i> Ehrenberg			X	
<i>Guinardia</i> sp.,		X		
<i>G. delicatula</i> Cleve		R		
<i>G. striata</i> Hasle		X	C	H
<i>Hemiaulus hauckii</i> Grunow				X
<i>H. membranaceus</i> Cleve				X
<i>H. sinensis</i> Greville		H	X	X
<i>Leptocylindrus</i> sp.,		X		
<i>L. danicus</i> Cleve	X	F	C	H
<i>Pseudosolenia calcar-avis</i> Schultz	X		H	F
<i>Rhizosolenia</i> sp.,	X	C		R
<i>R. alata</i> Cleve	X	H	C	F
<i>R. bergonii</i> Pérégallo		X	C	
<i>R. cochlea</i> Brun		X		
<i>R. delicatula</i> Cleve		X		
<i>R. hebetate</i> Hensen	H	F		C
<i>R. setigera</i> Brightwell		C	R	F
<i>R. shrubsolei</i> Cleve				C

Fig. 7. Seasonal abundance of Bacillariophyceae(A), Dinophyceae (B) and Cyanophyceae cell abundance at Sharm Yanbu lagoon of Saudi Arabia from spring to winter, 2016-2017.

Fig. 5. Variation of phytoplankton species diversity index (H) at Sharm Yanbu lagoon of Saudi Arabia from spring to winter, 2016-2017.

Fig. 6. Dynamics of phytoplankton cells abundance at Sharm Yanbu lagoon of Saudi Arabia from spring to winter, 2016-2017.

Fig. 3. Seasonal variation of pH at Sharm Yanbu lagoon of Saudi Arabia from spring to winter, 2016-2017.

Fig. 4. The fluctuation of chlorophyll *a* at Sharm Yanbu lagoon of Saudi Arabia from Spring to Winter, 2016-2017.

Fig. 1. Map of the study area showing different sampling stations of Sharm Yanbu lagoon, Saudi Arabia.

Fig.2. Seasonal variation of temperature (°C) at Sharm Yanbu lagoon of Saudi Arabia from spring to winter, 2016-2017.

Fig. 2. Seasonal variation of temperature (°C) at Sharm Yanbu lagoon of Saudi Arabia from spring to winter, 2016-2017.

at St.3, with the average of $0.49 \mu\text{g L}^{-1}$. $\text{SiO}_2\text{-Si}$ concentration varied from 0.21 to $6.28 \mu\text{g L}^{-1}$ and the average was $1.48 \mu\text{g L}^{-1}$, with the lowest concentration in autumn at St.5, and the highest in spring at St.4 (Table 1). Chlorophyll *a* concentration varied from 0.07 to $2.20 \mu\text{g L}^{-1}$ with an average of $0.39 \mu\text{g L}^{-1}$. The lowest and the highest concentration were in spring and in summer at St.4 and St.2, respectively (Fig. 4). Chlorophyll *a* showed significantly positive correlation with phytoplankton abundance in spring, summer and autumn ($r = 0.64$, $r = 0.59$ and $r = 0.66$), respectively.

3.2 Dynamics of Phytoplankton

During the present study the phytoplankton community was represented by a total of 168 species, among them; 94 belong to Bacillariophyceae, 69 Dinophyceae, 3 Cyanophyceae, 1 Chlorophyceae and 1 Mediophyceae (Table 2). The species diversity index (*H*) ranged from 2.25 to 4.21 with the average of 3.0. In spring, the highest '*H*' value was at St.6 while the lowest value was at St.2. Similarly, in summer, the highest '*H*' value was 3.67 at St.4 and the lowest was 3.13 at St.3. In autumn, the highest '*H*' value was 3.23 at St.5 and the lowest was 2.68 at St.3. Also, in winter, the lowest and highest '*H*' values were 2.76 and 2.92 at St.4. and St.6 (Fig. 5). Average phytoplankton cell abundance varied from 4.80×10^3 to $8.46 \times 10^3 \text{ cells.L}^{-1}$, the highest and lowest abundance was in spring and winter, respectively (Fig. 6.). Bacillariophyceae contributed 54.94%, of phytoplankton community composition, followed by Dinophyceae (40.07%), Cyanophyceae (3.79%), Chlorophyceae (0.60%) and Mediophyceae (0.60%).

The average cell abundance of Bacillariophyceae varied from 0.85×10^3 to

$2.48 \times 10^3 \text{ cells L}^{-1}$ with the highest abundance in summer, followed by spring (Fig. 7A). *Cylindrotheca closterium* and *Licmophora flabellata* of pennate diatoms constituted 15.89% and 11.20% of total phytoplankton in spring and summer, respectively. In winter, *Pseudonitzschia seriata* comprised 12.20 and 14.05% of total phytoplankton count. The centric diatoms contributed by 10.10-14.29% to the total phytoplankton count, especially due to the dominance of *Guinardia striata* in winter (Table 3). The average cell abundance of Dinophyceae varied from 2.97×10^3 to $5.51 \times 10^3 \text{ cells L}^{-1}$ with the highest value in spring, followed by summer and autumn (Fig. 7B). In spring, four species such as *Dinophysis acuminata*, *Prorocentrum lima*, *P. micans* and *Scrippsiella trochoidea* was found to contribute above 10% of total phytoplankton cell count. In summer, *Ceratium furca*, *Diplopsalis lenticular*, *Prorocentrum lima* and *P. micans* were the dominant species which contributed above 10% of cell abundance of total phytoplankton (Table 3). In autumn, *Ceratium furca*, *Dinophysis acuminata*, *Prorocentrum micans* and *Protoperidinium quinquecorne* were found to be dominant species which contributed more than 10% as a single species of phytoplankton cell count (Table 3). Similarly, in winter, *Ceratium furca*, *C. fusus*, *Dinophysis acuminata* and *Prorocentrum micans* were the dominant species, and as a single species they contributed more than 10% of phytoplankton cell count (Table 3). Cyanophyceae cell abundance varied from 0.14×10^3 to $0.90 \times 10^3 \text{ cells L}^{-1}$, and the higher cell abundance was found in spring and summer (Fig. 7C). *Oscillatoria* sp. of Cyanophyceae was found to be dominant comprising more than 10% of phytoplankton cell abundance from spring to autumn (Table 3).

summarized as cells per liter. Finally, the results were used for graphical presentation. For taxonomic identification, the sample was observed under inverted light microscope (MEIJI, JAPAN). Taxonomic identifications were done based on the morphological characteristics described by Tomas (1993, 1997), Shim (1994), Kobayasi (2006), Sournia (1986) and Al-Kandari (2009). Frequency index of a particular species was estimated by $f = m/M \times 100$, where m = number of stations where the species were found and M = number of all stations. Species diversity was calculated following Shannon index, 'H' which is also called Shannon-Wiener index or Shannon-Weaver index (Shannon and Weaver, 1949). It is the most widely used index for measuring biological diversity;

$$H = - \sum_{i=1}^S P_i \ln P_i$$

Where

S = total number of species

$P_i = N_i/N$ = proportion of individuals of the total sample belong to i th species

N_i = number of individuals (N) belonging to the i th species

N = total number of individuals

2.3 Physico-Chemical Factors Analysis

The water temperature and pH were measured in situ with HACH multimode salinometer (HACH 58258-00, Germany). For chlorophyll analysis, about 5 L seawater sample was filtered through GF/C 47 mm Whatman paper using the vacuum pressure electrical pump. Thereafter, the filtered paper was used for chlorophyll a estimation and the filtered water was kept in deep freeze at -20°C for chemical analysis. The chlorophyll a was estimated following the methods described by Parsons *et al.* (1984). The frozen samples were taken of and kept in ambient

temperature for melting in dark room. Then, melted water samples were used for chemical analysis to estimate the nutrients concentrations. The nutrients such as $\text{NO}_3\text{-N}$, $\text{NO}_2\text{-N}$, $\text{NH}_4\text{-N}$, $\text{PO}_4\text{-P}$ and $\text{SiO}_2\text{-Si}$ were estimated spectrophotometrically (Shimadzu UV-1201, Japan) according to the methods described by Parsons *et al.* (1984). Pearson's correlation was determined using MS Excel statistical analysis program.

3. Results

3.1 Dynamic of Physical and Chemical

During this study, seawater temperature showed maximum values in summer, followed by autumn, spring and winter. Temperature varied from 22.00°C to 33.30°C with average of 26.90°C . The maximum and the minimum values were at same station (St.1) (Fig. 2.).

The present study revealed that the pH values of the investigated sites were on the alkaline side. pH fluctuated between 8.49 and 8.81, and the average value was 8.67 throughout the study (Fig. 3). The pH and temperature showed significantly positive correlation ($r = 0.66$) in spring and non-significant negative correlation in summer ($r = -0.30$).

The concentration of $\text{NH}_3\text{-N}$ varied from 0.08 to $2.02 \mu\text{g L}^{-1}$ with an average of $0.37 \mu\text{g L}^{-1}$, and the lowest and the highest concentrations were at St.4 and St.2 in spring and autumn, respectively. $\text{NO}_2\text{-N}$ concentration fluctuated between 0.09 and $2.21 \mu\text{g L}^{-1}$ among stations during study, and the minimum and maximum values were in winter at St.6 and autumn at St.4. $\text{NO}_3\text{-N}$ concentration varied from 0.20 to $1.28 \mu\text{g L}^{-1}$ with an average of $0.55 \mu\text{g L}^{-1}$. The minimum value was at St.5 in winter and maximum was at St.4 in autumn. The lowest concentration of $\text{PO}_4\text{-P}$ ($0.19 \mu\text{g L}^{-1}$) was found at St.6 in autumn and the highest ($1.51 \mu\text{g L}^{-1}$) in spring

Therefore, a study on phytoplankton dynamics in relation with environmental factors was conducted at Sharm Yanbu lagoon of the Red Sea, the Kingdom of Saudi Arabia. Yanbu is located in the western part of the Kingdom of Saudi Arabia. It is rapidly growing city with huge industries and petroleum refineries companies such as Saudi Aramco, Sabic and others. It has two ports such Yanbu Commercial Port and King Fahad Industrial Port. The city is divided into three cities: Yanbu Al Nakhl, Yanbu Al Bahr and Yanbu Industrial. Sharm Yanbu lagoon has been declared as an environment sensitive area by the General Authority for Meteorology and Environmental Protection of the Kingdom of Saudi Arabia, and the International Union for Conservation of Nature and Natural Resources (IUCN). It is connected to the Red Sea with wide channel (Al-Barakati, 2012). Thus, its physico-chemical factors might be influenced by the Red Sea water mass. The Red Sea is narrow oceanic basin and is located between the Asian and the African continental shelves. It is considered the highest saline water body in the world's seas with the deep-water salinity of 40.06 psu and surface water salinity ranged from 40.10 to 40.65 psu. There is no river run off into the Red Sea and scanty rain fall from October to May. The negative hydrological budget of Red Sea is compensated by inflows from the Indian Ocean through Bab-Al-Mandab (Marcos 1970). It is considered as an oligotrophic water body. Nutrients are generally introduced by water intrusion from the Gulf of Aden through Bab-Al-Mandab or via aerial deposition to the Red Sea.

However, about 500,000 people are living in Yanbu city. There are many places for recreation, like beach activities, plenty of hotels, restaurants, amusement parks, fishing and picnic spots. The anthropogenic activities might have changed the natural environmental conditions of the lagoon than previous.

Moreover, there is no published report on the study of phytoplankton in relation with environmental factors. Therefore, this study was conducted to find out the phytoplankton community composition, abundance and seasonal dynamics in relationship with environmental factors.

2. Materials and Methods

2.1 Study Area and Sampling

Yanbu belongs to Madinah province of the Kingdom of Saudi Arabia. The estimated area of Sharm Yanbu lagoon is approximately ($7.5 \times 106 \text{ m}^2$) and volume of $37.5 \times 106 \text{ m}^3$, the maximum depth of about 20 m and the average is 5 m. It is connected to the open sea by a channel of about 250 m with an average depth of about 17 m (Al-Barakati 2012). Samples were collected in May (Spring), August (Summer) and November (Autumn) of 2016 and February (Winter) of 2017 at 6 stations. The stations were St.1 ($24^\circ 10' 06.6''\text{N}$, $37^\circ 58' 39.9''\text{E}$), St.2 ($24^\circ 09' 58.5''\text{N}$, $37^\circ 57' 25.9''\text{E}$), St.3 ($24^\circ 12' 02.0''\text{N}$, $37^\circ 56' 24.6''\text{E}$), St.4 ($24^\circ 10' 34.0''\text{N}$, $37^\circ 55' 45.1''\text{E}$), St.5 ($24^\circ 09' 13.9''\text{N}$, $37^\circ 56' 20.1''\text{E}$) and St.6 ($24^\circ 08' 38.0''\text{N}$, $37^\circ 55' 44.4''\text{E}$) (Fig. 1). Water samples were collected for the analysis of phytoplankton, nutrients and chlorophyll *a*. For phytoplankton study, 150 L water samples were filtered manually through phytoplankton net with 10 μm mesh size (Hydro-Bioas, Germany) at each sampling station, concentrated to 500 mL and fixed with 2% of Lugol's iodine solution.

2.2 Phytoplankton Analysis

For quantitative study, three aliquots of a 1 mL sample were taken after mixing and counted in a Sedgewick-Rafter (S-R) counter chamber with a light microscope. Counted results were converted to the abundance of phytoplankton of original natural seawater following retrospective calculation and

Seasonal Dynamics and Diversity of Phytoplankton in Sharm Yanbu Lagoon, Red Sea, Saudi Arabia

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Abstract. Yanbu is considered one of the most important industrial and touristic areas on Saudi coast of the eastern side of the Red Sea. It is a developing and expanding city with modern facilities and industries which can affect the coastal environment and influence the qualitative and quantitative dynamics of the phytoplankton community. The present study was carried seasonally on the species composition and abundance of phytoplankton concurrently with the surrounding physico-chemical conditions of Sharm Yanbu lagoon. The results revealed that water temperature ranged 22.00°C and 33.30°C, and chlorophyll a concentration of 0.07–2.20 µg.L⁻¹. A total of 168 phytoplankton species were identified, including 94 Bacillariophyceae, 69 Dinophyceae, 3 Cyanophyceae, 1 Chlorophyceae and 1 Mediophyceae. Cell abundance varied from 2.34×10³ to 12.07×10³ cells.L⁻¹, with the highest count occurred in spring and the lowest in winter. Bacillariophyceae contributed (54.95%), followed by Dinophyceae (40.07%), Cyanophyceae (3.79%), Chlorophyceae (0.60%) and Mediophyceae (0.60%) to total of phytoplankton. Among Bacillariophyceae, the pennate forms constituted 32.34% and centric 22.28%. Phytoplankton exhibited positive correlation with chlorophyll a in spring, summer and autumn (r = 0.64, r = 0.59 and r = 0.66), respectively.

Keywords: Phytoplankton, Environmental factors, Community composition, Dynamics, Diversity.

1. Introduction

Phytoplankton contribute a major portion of primary production. They support food webs in waters ranging from tiny ponds to oceans, they are responsible for 46% of global productivity (Field *et al.*, 1998). The seasonal and temporal variability in the structure and function of the phytoplankton community occur due to interactions among physical, chemical, and biological variables, resulting in frequent reorganization of the relative abundance and species composition of phytoplankton (Reynolds *et al.*, 2000). Water temperature plays an important role to control the algal growth in natural environments (Lund 1949; Talling 1955).

The predominance of phytoplankton species also depends on optimum growth temperature (Harris 1986). In addition, temperature and variability of nutrients can alter the species composition of primary producers (Roelke *et al.*, 1999). Temporal changes in nutrients supply had the effect on phytoplankton species diversity (Sommer 1995; Sommer and Floder 1999). However, there are growing evidence that human activities are altering the distribution and movements of nutrient elements, resulting in increasing nutrients loads to receive waters and change in phytoplankton community composition, abundance and dynamics (NRC, 2000; Roelke *et al.*, 1999).

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