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Models for estimating phytoplankton population densities under different environmental conditions with emphasis on climatic factors

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Abstract

The aim of this study is to determine the effect of environmental conditions with emphasis on the main meteorological factors (air temperature variables, sunshine hour, and humidity), on phytoplankton communities. As important primary producers in aquatic ecosystems, phytoplankton communities could be affected by several factors. Environmental factors play the major role in occurrence and diversity of these photosynthetic microorganisms. In the present study, the relationship between phytoplankton occurrence and meteorological variables was assessed in several artificial ponds and lakes in the National Botanical Garden of Iran. For this purpose, surface water samples of the selected sites were monthly studied over a year. A total of 122 taxa of phytoplanktons were identified in the mentioned sites out of which, five taxa were new records for Iran. Among several taxa, six dominant genera, including *Chroococcus* (Cyanophyta), *Nitzschia* (Bacillariophyta), *Glenodinium* (Pyrrhophyta), *Scenedesmus*, *Cosmarium*, and *Tetraedron* (Chlorophyta), were selected for further investigation. The meteorological factors were considered with emphasis on air temperature variables (maximum and minimum temperatures, average air temperature, wet and dry temperatures, and dew point temperature), sunshine hour, and humidity. Results showed that, climatic conditions can be considered as effective factors on phytoplankton communities. The results of regression analysis between algal density and meteorological variables showed that, phytoplankton's density has a significant correlation with the sunshine hour and air temperature variables. It seems that, the regression equation and environmental sensitivity vary from one taxon to another.

Keywords: Algal flora, freshwater ecosystem, light intensity, meteorology, population density

ارایه مدل‌هایی برای تخمین تراکم جوامع فیتوپلانکتونی متاثر از شرایط محیطی با تاکید بر عوامل اقلیمی

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خلاصه

جوامع فیتوپلانکتونی، به عنوان گروه مهمی از تولیدکنندگان اولیه در اکوسیستم‌های آبی، تحت تاثیر عوامل مختلفی قرار دارند. بی‌تردید فاکتورهای محیطی نقش مهمی در فراوانی و تراکم این میکروارگانیسم‌های فتوسنتزکننده اعمال می‌نمایند. در این مطالعه، ارتباط میان فراوانی جوامع فیتوپلانکتونی و متغیرهای هواشناسی، در تعدادی از اکوسیستم‌های آبی واقع در باغ گیاه‌شناسی ملی ایران (مؤسسه تحقیقات جنگل‌ها و مراتع کشور، تهران) مورد ارزیابی قرار گرفت. به این منظور، نمونه‌هایی از آب سطحی اکوسیستم‌های آبی مورد نظر به صورت ماهانه و به مدت یک سال بررسی گردید. در مجموع، ۱۲۲ آرایه فیتوپلانکتونی شناسایی شد که از آن میان، پنج آرایه برای نخستین بار از ایران گزارش می‌شوند. به منظور ارزیابی چگونگی تاثیرپذیری جوامع فیتوپلانکتونی از متغیرهای هواشناسی، شش جنس غالب از اکوسیستم‌های مورد نظر به اسامی *Chroococcus* (Cyanophyta)، *Nitzschia* (Bacillariophyta)، *Glenodinium* (Pyrrhophyta)، *Scenedesmus*، *Cosmarium* و *Tetraedron* (Chlorophyta) مورد بررسی قرار گرفتند. از جمله متغیرهای هواشناسی مورد مطالعه می‌توان به متغیرهای دمایی (دمای بیشینه و کمینه، دمای میانگین، دمای خشک و مرطوب و دمای شبنم)، تعداد ساعات آفتابی و شرایط رطوبتی اشاره نمود. نتایج این مطالعه نشان داد که عوامل اقلیمی از جمله عوامل مهم تاثیرگذار بر جوامع فیتوپلانکتونی هستند. همچنین، نتایج تحلیل وایازشی (آنالیز رگرسیون) تراکم جلبکی و متغیرهای هواشناسی نشان داد که تراکم فیتوپلانکتونی دارای همبستگی معنی‌داری با تعداد ساعات آفتابی و متغیرهای دمای هوا می‌باشد. از دیگر نتایج مطالعه حاضر، می‌توان به اختلاف روابط وایازشی (رگرسیون) و حساسیت‌های محیطی نمونه‌های مختلف در مقایسه با یکدیگر نیز اشاره نمود.

واژه‌های کلیدی: اکوسیستم آب شیرین، تراکم جمعیت، شدت تابش، فلور جلبکی، هواشناسی

Introduction

Phytoplanktons are the microscopic forms of algae which are functioning as one of the most important part of food chain in aquatic ecosystems. Several environmental factors affect phytoplankton diversity and abundance in ponds, lakes or other water reservoirs. In recent decades, issues such as phytoplankton's response to the environmental change have attracted the attention of many researchers and ecologists. The phytoplankton communities' response to irradiance, temperature, vertical mixing of water column as well as nutrient gradient in water, has been one of the hot research topics in the last decades (Geider *et al*. 1997, Tirok & Gaedke 2007, Grimaud *et al*. 2015). In this regard, several models have been developed to demonstrate the effect of environmental factors on growth and distribution of these photosynthetic microorganisms (Grimaud *et al*. 2015, Grover & Chrzanowski 2006). In majority of these models, environmental factors such as temperature or light intensity are introduced as the most important factors (Tirok & Gaedke 2007). It should be noted that, the mentioned factors are under strong influence of the climatic conditions and seasonal shift. Seasonal shift strongly affects various environmental factors such as temperature, sunshine hour, zooplankton communities and nutrient availability in aquatic ecosystems. Undoubtedly, temperature variations in different seasons can be considered as the most important factor affecting biodiversity in these ecosystems. Striebel *et al*. (2016) showed that, temperature has a drastic influence on phytoplankton communities by affecting the biotic and abiotic factors in aquatic ecosystems. Lewandowska *et al*. (2014) also indicated that, warming has positive effects on phytoplankton biomass but can have strong negative impact by decreasing nutrient flux at higher temperature. In the other study, Grimaud *et al*. (2015) tried to model the effect of temperature on phytoplankton growth and showed that, the optimal temperature for phytoplankton growth has a strong correlation with thermal amplitude variation. It must be emphasized that temperature does not always directly affect phytoplankton communities. For example, diatom communities are often frequent in the seasons of the year with well mixed water column such as spring and autumn; and temperature is one of the important factors in the formation of water flow in these seasons. Instead, the green algae and cyanobacteria are directly dependent on water temperature, as these groups of photosynthetic organisms have higher optimum temperature need (Staehr & Sand-Jensen 2006).

Light intensity is another environmental factor which can change by seasonal shift and climate change. The amount of light absorbed by several groups of algae in phytoplankton communities is strongly linked to the ambient light need of each taxon. Therefore, this environmental factor can be used as an important index in designing models to describe the role of the environment in quality and quantity of phytoplankton communities. Several studies also have emphasized on this correlation (Carlos *et al*. 1999, Lonin & Tuchkovenko 2001).

The effect of meteorological and climatological conditions on bio-ecosystems is the major challenge of the agronomy and aquaculture. In the other words, meteorology is an important tool for management of water resources. In general, the bio-meteorological modelling is the modern and efficient approach to analyze the effects of environmental factors on bio-agents behavior in each ecosystem. Although, numerous studies have shown the effects of several abiotic agents on the growth and activity of phytoplankton, not much attention has been paid to the impact of climatic conditions on specific taxa. Undoubtedly, determining the relative importance of environmental factors in controlling the distribution and diversity of several taxa in phytoplankton communities which can play an important role in different research fields such as management of water resources and aquaculture research. Therefore, the aim of this study is to determine the effect of environmental conditions with emphasis on the main meteorological factors (air temperature variables, sunshine hour, and humidity), on phytoplankton communities. We expect that, the results of present study, will contribute in better understanding of dominant phytoplankton's behavior in aquatic ecosystems for efficient management of water resources in particular freshwater resources.

Materials and Methods

- Study area and water sampling procedure

Water sampling was monthly conducted (12 months) from four aquatic sites located at the National Botanical Garden of Iran (Research Institute of Forests and Rangelands, Tehran, Iran) (Fig. 1).

At each site (Table 1), three samples were collected in a 1-liter bottle from 0.5 m depth of shore line. Water temperature and pH were measured immediately after collection. All samples were preserved with 4% formaldehyde solution for further analysis and carried to the laboratory in cool containers. Phytoplankton samples were allowed to settle for at least seven days and the super liquid section removed. Finally, each sample was concentrated to 125 ml.

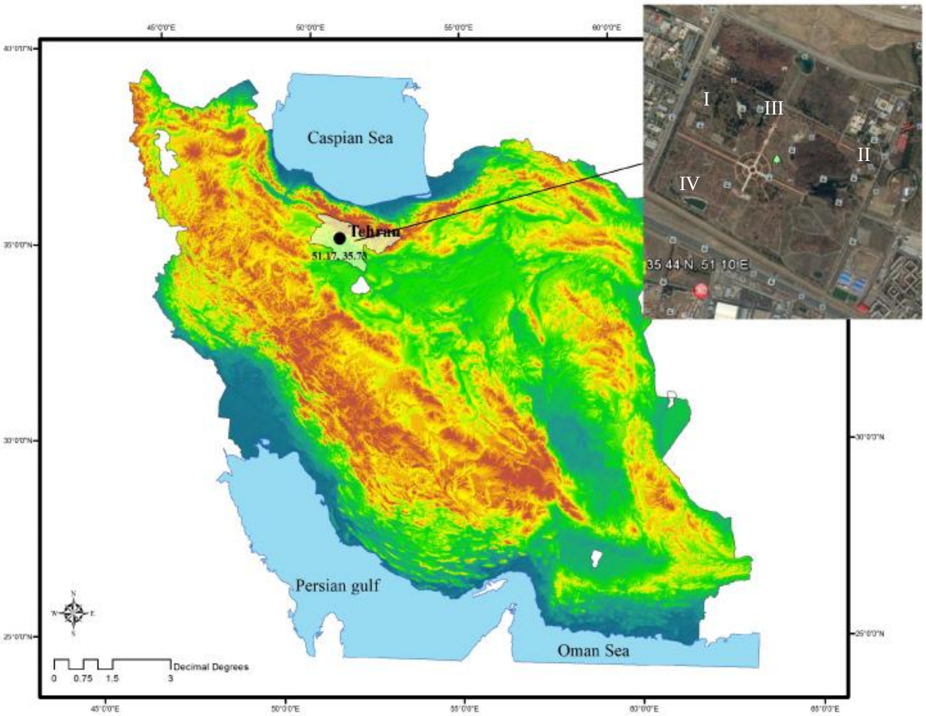

Fig. 1. The location of study area.

Table 1. Approximate area and depth of study sites

Site	Location	Pond area (m^2)	Pond depth (m)
1	35° 44′ 32″ N, 51° 10′ 23″ E	2500	2.5
2	35° 44′ 14″ N, 51° 10′ 34″ E	102	1.2
3	35° 44′ 31″ N, 51° 10′ 28″ E	3000	2.5
4	35° 44′ 17″ N, 51° 10′ 07″ E	1975	1.5

- Identification of phytoplanktons

Taxonomic determination was carried out by morphometric study of taxa with light microscopy based on Prescott (1970), Whitford & Schumacher (1973), Wehr *et al*. (2002), John *et al*. (2002), and Komárek & Anagnostidis (2005) methodology by prepared semi-permanent slides. The vegetative and reproductive characters used in the taxonomic determination were selected on the basis of specific descriptions of genera and species.

- Enumeration of phytoplanktons

Enumeration of phytoplankton populations was performed according to the procedure described by Andersen (2005). The Sedgwick-Rafter counting chamber was used for this purpose.

- Meteorological data

The meteorological data sets used in this study were obtained from the Iran Meteorological Organization (IRIMO) in the time period matching with water sampling time. Chitgar is the nearest meteorological station to the sampling sites locating on $35^{\circ}\ 44'$ N and $51^{\circ}\ 10'$ E in elevation of 1300 m from sea level. The data set is consisting of monthly air temperature variables (maximum and minimum temperature (T_{max}, and T_{min}), average air temperature (T_{mean}), wet and dry temperature (T_{wet}, and T_{dry}), dew point temperature (T_{dew}), monthly sunshine hour (S), monthly total precipitation (R), and monthly relative humidity (R_h). The weather data set was constructed after the homogeneity and quality control tests.

- Meteorological analysis and modelling method

The influence of meteorological conditions on algal density was investigated by model construction. For this order, multiple stepwise regression analysis was performed and the best subset was selected. The correlation of each meteorological variable and their best subset were tested by Minitab16 and the solver toolbox of Microsoft excel. These tools were used to analyze the relationships between algal density and meteorological variables with multivariate analyzing.

Results

In the present study, representative water samples were collected from several freshwater ponds located in the western part of Tehran province, Iran (Table 1). In total, 122 taxa were identified which belong to six phylum and several families (Table 2). Among isolated taxa, *Drepanochloris nannoselene* (Skuja) Marvan, Komárek & Comas, *Desmodesmus maximus* (West & G.S. West) Hegewald, *Desmodesmus armatus* var. *longispina* (Chodat) E. Hegewald, and *Tetradesmus bernardii* (G.M. Smith) M.J. Wynne from Chlorophyta, and *Dactylococcopsis fascicularis* Lemmermann from Cyanophyta are reported as new records in Iran.

Description of new records

1. ***Drepanochloris nannoselene*** (Skuja) Marvan, Komárek & Comas (1984)

Cells solitary, small, lunate or arcuate; cells 2.5 µm in diameter; 2.5–5 µm between apices (Fig. 2a).

General distribution: Europe (Balearic Islands, Britain, France, Spain, Sweden); North and South of America (Mexico, Brazil) (http://www.algaebase.org/).

2. ***Tetradesmus bernardii*** (G.M. Smith) M.J. Wynne (2016)

Thallus in the form of colony; colony composed of 4–8 fusiform or lunate cells; cells adjoined alternately by the apex of one cell to the middle of the next in series; cells without spiny projections, 2.5 µm in diameter, 10 µm long (Fig. 2b).

General distribution: Europe (Britain, France, Germany, Netherlands, Romania, Slovakia, Turkey); America (Northwest Territories, Great Lakes, Brazil); Asia (India, Iraq, Russia, China, Taiwan, Turkey); Australia and New Zealand (Northern Territory); Africa (Ghana) (http://www.algaebase.org/).

Table 2. Diversity of algae in sampling sites

Taxon	Site 1	Site 2	Site 3	Site 4
Chlorophyta				
Binuclearia sp.	•		•	
Chlamydocapsa planctonica (West & G.S. West) Fott	•			
Cladophora sp.	•		•	
Closterium dianae var. *pseudodianae* (J. Roy) Willi Krieger				•
C. littorale F. Gay	•			•
C. moniliferum Ehrenberg ex Ralfs		•		•
C. parvulum Nägeli				•
Closterium sp.			•	
Cosmarium botrytis Meneghini ex Ralfs		•		•
C. botrytis var. *gemmiferum* (Brébisson) Nordstedt		•	•	•
C. botrytis var. *tumidum* Wolle	•	•		
C. circulare Rinsch	•	•	•	
C. exiguum W. Archer				•
C. granatum Brébisson ex Ralfs			•	
C. obtusatum (Schmidle) Schmidle		•	•	
C. parvulum Brébisson				•
C. pokornyanum (Grunow) West & West			•	
C. pyramidatum Brébisson ex Ralfs		•	•	•
C. pyramidatum var. *convexum* Willi Krieger & Gerloff	•		•	
C. subreniforme Nordstedt	•		•	•
Cosmarium sp.$_1$	•			•
Cosmarium sp.$_2$			•	
Desmodesmus armatus var. *longispina* (Chodat) E. Hegewald*	•	•		
D. maximus (West & G.S. West) Hegewald*		•		
Drepanochloris nannoselene (Skuja) Marvan, Komárek & Comas*	•			•
Euastrum sp.			•	•
Klebsormidium montanum (Hansgirg) Shin Watanabe			•	
Mougeotia scalaris Hassall	•			
Mougeotiopsis sp.			•	
Oedogonium sp.	•	•		•
Oocystis borgei Snow			•	
O. elliptica W. West	•		•	
O. pusilla Hansgirg	•		•	
O. solitaria Wittrock	•		•	
Oocystis sp.	•			
Pandorina sp.	•	•		•
Pediastrum boryanum var. *brevicorne* A. Braun			•	
P. duplex Meyen		•		
P. duplex var. *cohaerens* Bohlin		•		
P. integrum Nägeli				•
Pediastrum sp.			•	
Planktosphaeria gelatinosa G.M. Smith		•		
Pseudopediastrum boryanum (Turpin) E. Hegewald		•		
Scenedesmus maximus (West & G.S. West) Chodat	•	•		
S. naegelii Brébisson	•	•		
S. parvus (G.M. Smith) Bourrelly	•			
S. quadricauda (Turpin) de Breb	•	•		
S. quadrispina Chodat		•	•	

Table 2 (contd)

S. raciborskii Woloszynska	•		•	•
Selenastrum capricornutum Printz				•
Tetradesmus bernardii (G.M. Smith) M.J. Wynne*		•		
T. dimorphus (Turpin) M.J. Wynne	•		•	
T. lagerheimii M.J. Wynne & Guiry	•		•	
Tetraedron minimum (A. Braun) Hansgirg	•	•	•	•
Trentepohlia aurea (Linnaeus) C. Martius	•		•	•
Trochiscia reticularis (Reinsch) Hansgirg			•	•
T. zachariasii Lemmermann		•	•	•
Ulothrix sp.			•	
Volvox sp.			•	•
Cyanophyta				
Aphanothece castagnei (Kützing) Rabenhorst				•
A. stagnina (Sprengel) A. Braun in Rabenhorst			•	
Chroococcus dispersus (Keissler) Lemmermann			•	
C. minor (Kützing) Nägeli			•	•
C. pallidus Nägeli	•			
C. varius A. Braun in Rabenhorst				•
Dactylococcopsis fascicularis Lemmermann*	•			
Gloeocapsa rupestris Kützing				•
Jaaginema angustissimum (West & G.S. West) Anagnostidis & Komárek		•	•	
Lyngbya natans Hansgirg				•
Merismopedia punctata Meyen	•			
M. tenuissima Lemmermann		•		•
Microcystis aeruginosa (Kützing) Kützing				•
Oscillatoria subbrevis Schmidle	•			
Phormidium articulatum (N.L. Gardner) Anagnostidis & Komárek			•	•
P. tergestinum (Rabenhorst ex Gomont) Anagnostidis & Komárek Anagnostidis&Komárek			•	
Planktothrix prolifica (Gomont) Anagnostidis & Komárek		•		•
Pseudanabaena limnetica (Lemmermann) Komárek			•	
Spirulina sp.$_1$		•		
Spirulina sp.$_2$	•			
Euglenophyta				
Euglena elongata Schewiakoff				•
Chrysophyta				
Dinobryon sertularia Ehrenberg	•			
Pyrrhophyta				
Glenodinium borgei (Lemmermann) Schiller		•		
G. penardiforme (Lindemann) Schiller	•			
Peridiniopsis kulczynskii (Woloszynska) Bourrelly	•			
Peridinium cinctum (O.F. Müller) Ehrenberg		•		
Bacillariophyta				
Achnantheiopsis delicatula (Kützing) Lange-Bertalot		•		
Achnanthidium exiguum (Grunow) Czarnecki			•	
A. minutissimum (Kützing) Czarnecki		•		
Anomoeoneis sphaerophora Pfitzer				•
Cosmioneis pusilla (W. Smith) D.G. Mann & A.J. Stickle Round	•			
Craticula accomoda (Hustedt) D.G. Mann		•		

Table 2 (contd)

Cyclotella meneghiniana Kützing	•			
Cymatopleura solea (Brébisson) W. Smith		•		
Cymbella sp.				•
Cymbopleura naviculiformis (Auerswald ex Heiberg) Krammer	•		•	
Denticula kuetzingii Grunow	•		•	•
D. tenuis Kützing	•		•	•
Denticula sp.	•		•	•
Encyonema elginense (Krammer) D.G. Mann				•
Fragilaria acus (Kützing) Lange-Bertalot		•	•	
Fragilaria sp.			•	
Gomphonema sp.	•			
Gyrosigma acuminatum (Kützing) Rabenhorst		•		
Melosira varians C. Agardh	•			
Navicula cincta (Ehrenberg) Ralfs	•			
N. cryptocephala Kützing				•
N. gregaria Donkin		•		
N. phyllepta Kützing	•			•
Nitzschia baciliformis Hustedt				•
N. communis Rabenhorst				•
N. fonticola (Grunow) Grunow	•	•	•	•
N. fossilis (Grunow) Grunow			•	
N. hantzschiana Rabenhorst	•			
N. linearis W. Smith				•
N. palea (Kützing) W. Smith	•	•	•	•
N. paleacea (Grunow) Grunow	•			
N. radicula Hustedt				•
N. recta Hantzsch ex Rabenhorst				•
N. subacicularis Hustedt	•			
N. supralitorea Lange-Bertalot				•
Psammothidium pseudoswazii (J.R. Carter) L. Bukhtiyarova & Round		•		
Surirella sp.				•

* New record for Iran

3. *Desmodesmus maximus* (West & G.S. West) Hegewald (2000)

Colony of four elliptical or oblong cells lying side by side in a single series; cells 5 µm in diameter, 15–17 µm long; terminal cells with long curved spiny projections, spines more than 15 µm long (Fig. 2c).

General distribution: Europe (Netherlands, Romania, Slovakia, Turkey, Russia, Spain, Sweden); America (Aleutian Islands, Great Lakes, Mexico, Tennessee, Brazil); Asia (India, China, Taiwan, Turkey); Africa (Sudan); Australia and New Zealand (http://www.algaebase.org/).

4. *Desmodesmus armatus* var. ***longispina*** (Chodat) E. Hegewald (2000)

Colony of 4–8 elliptical cells lying side by side in a single series; cells 5 µm in diameter, 12–15 µm long; terminal cells with spiny projections, spines up to 6 µm long (Fig. 2d).

General distribution: Europe (Germany, Netherlands, Poland, Portugal, Romania, Slovakia, Spain, Sweden, Baltic Sea, Turkey); America (Québec, Arkansas, Great Lakes, Argentina); Asia (India, Taiwan, Singapore); Australia and New Zealand (New Zealand) (http://www.algaebase.org/).

5. *Dactylococcopsis fascicularis* Lemmermann (1898)

Cells colonial, rarely solitary; colonies composed of 3–4 elongate, spirally sigmoid cells tapering to fine points at the ends, compactly twisted; 1.5 µm in diameter, 25–30 µm long (Fig. 2e).

General distribution: Europe (Georgia, Lithuania, Romania, Turkey); America (Arkansas, Great Lakes, Québec, Argentina); Asia (India, Iraq, Russia, Taiwan) (http://www.algaebase.org/).

After identification and enumeration of taxa, the best multivariable equation for dominant genera was obtained and analyzed. The equation for each taxon is shown in Table 3. In the present study, the representative taxa were selected from four phyla *viz.* Chlorophyta, Bacillariophyta, Pyrrhophyta, and Cyanophyta (Fig. 3).

Among them, *Chroococcus* was considered as the representative of Cyanophyta (Cyanobacteria). It is necessary to mention that, this genus was the dominant taxon of this phylum in the studied sites. *Chroococcus* is a unicellular or colonial algae with colonies usually forming macroscopic and gelatinous mats mainly in aquatic freshwater ecosystems (Fig. 3d). In the model achieved for this genus (N=26.679T_{min}^2–220.84T_{min}+1083.6), the cell number (N) was a parabolic function of minimum temperature (Table 3). It means, the cell number of taxa initially decreased and then increased proportional to T_{min}. The plot of observed and estimated values of cell number showed that, these two variables were highly correlated (R^2=0.918) and their relationship was significant in 5% level (Figs 4a & b).

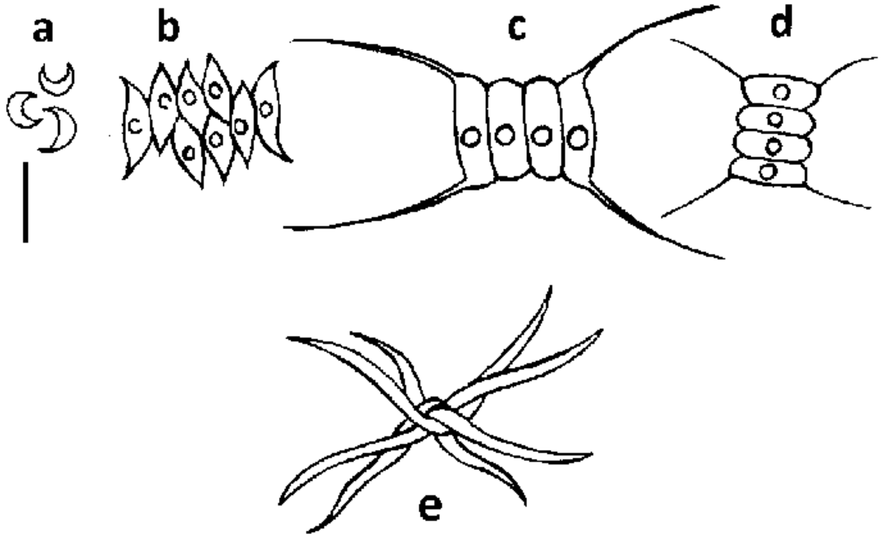

Fig 2. a. *Drepanochloris nannoselene*, b. *Tetradesmus bernardii*, c. *Desmodesmus maximus*, d. *Desmodesmus armatus* var. *longispina*, e. *Dactylococcopsis fascicularis* (Bar = 5 µm).

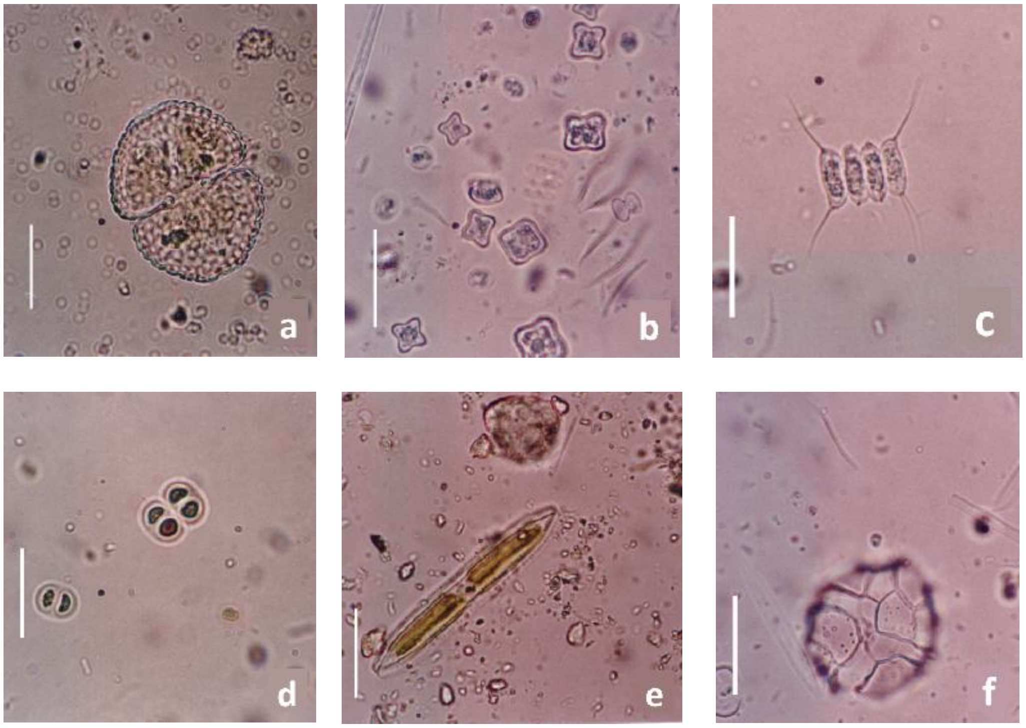

Fig. 3. The representative genera selected for ecological study: a. *Cosmarium*, b. *Tetraedron*, c. *Scenedesmus*, d. *Chroococcus*, e. *Nitzschia*, f. *Glenodinium* (Bar = 5 µm).

Glenodinium is other taxon which was selected as a dominant Pyrrhophyta in studied sites. This genus is a flagellate, single-celled alga which lives in marine and freshwater habitats (Fig. 3f). Distribution of this dinoflagellates alga depends on temperature, salinity or water depth of aquatic ecosystems. The result of this study showed that, the cell density of this genus was a linear function of daily mean temperature (Table 3). It means, the cell number of *Glenodinium* species increased with T_{mean} as a linear function ($N=93.873T_{mean}-247.04$). This equation was significant in 5% level and the coefficient determination of estimated-observed values which was 0.86 (Figs 4d & e).

Nitzschia as a common pennate diatom was another dominant taxon which was selected for the present study (Fig. 3e). In general, diatoms are a major group of planktonic algae which are found growing as unicellular or colonial forms in aquatic ecosystems. In scatter plot of *Nitzschia* with meteorological variables, the cell number did not show significant correlation with meteorological variables (Table 3). For example, the *Nitzschia* cell number was plotted against mean daily temperature and sunshine hour fraction (Fig. 4i, j). Both plots showed very poor correlation and the coefficient determination in each equation (0.096 and 0.08, respectively). This correlation was checked for other meteorological variables. The final result showed that, this genus was not significantly correlated with meteorological variables.

Due to the abundance and variety of green algae (Chlorophyta) in the studied sites, three taxa from this group were also considered for the present study, namely, *Scenedesmus*, *Cosmarium*, and *Tetraedron*.

Scenedesmus is a single-celled or colonial form of green algae with capitate, obtuse, acute or long tapering cell poles (Fig. 3c). *Scenedesmus* cell number (*N*) was a parabolic function of sunshine hour fraction (Table 3). This means that, the cell number of these taxa initially decreased and then increased proportional to sunshine hour fraction. The coefficient determination of this equation was 0.944 and the achieved function was significant in 5% level (Fig. 4g, h).

Cosmarium is also a single-celled green alga with shallow to deep median constriction (Fig. 3a). This genus occasionally exists in subaerial or in eutrophic water. The algal cell density of this genus was a linear function of two variables. Sunshine hour fraction and dew point temperature (T_{dew}) were the meteorological variables which affected *Cosmarium* cell density (N=–4.7+10.4(S)+7.38T_{dew}). The coefficient determination of this equation was 0.95 and the achieved function was significant in 5% level (Fig. 4c).

Table 3. Proposed regression equation in sampling sites

Genus	**Function**		**Meteorological variables**							
		R^2	**T_{mean}**	**T_{min}**	**T_{max}**	**T_{dry}**	**T_{dew}**	**RH**	**S**	**R**
Chroococcus (Cyanoprokaryota)	N=26.679T_{min}^2–220.84T_{min}+1083.6	0.92		●						
Glenodinium (Dinophyta)	N=93.873T_{mean}–247.04	0.86	●							
Nitzschia (Bacillariophyta)	N=12.287T_{mean}+27.475	0.09								
Scenedesmus (Chlorophyta)	N=70.74(S)^2–825.16(S)+2305	0.94							●	
Cosmarium (Chlorophyta)	N=–4.7+10.4(S)+7.38T_{dew}	0.95					●		●	
Tetraedron (Chlorophyta)	N=3835–1606T_{min}+738(S)–2324T_{max}+4008T_{dry}	0.92		●	●	●			●	

Similarly, *Tetraedron* is a single-celled green alga from Chlorophyta with flattened or triangular, quadrangular or polygonal cells (Fig. 3b). The taxa of this genus constructed planktonic communities in freshwater ecosystems. The population of this genus was a polynomial function of temperature and sunshine hour (N=3835–1606T_{min}+738(S)–2324T_{max}+4008T_{dry}). The relationship between estimated and observed values was shown in Fig. 4f. The achieved function was significant in 5% level with coefficient determination of 0.92.

Discussion

Among the identified taxa, several phytoplanktons and benthic species was observed, among which phytoplanktons showed the highest diversity and abundance. It should be noted that, some taxa such as *Scenedesmus* spp. are from euplanktonic algae, but another taxa can be seen in both forms in aquatic ecosystems. For example, the genus *Nitzschia* exists in benthic form as well as planktonic form. It seems that, the high rate of cell division in some seasons and special responses of several taxa to different environmental and physiological conditions are the most influential factors in this behavior (Javaheri *et al*. 2015).

Several environmental factors can affect phytoplankton diversity in each aquatic ecosystem. Although, several models have introduced biotic factors such as grazing agent as the final controllers of phytoplankton communities and their biomass in aquatic ecosystems (Norén *et al*. 1999, Marshalonis & Pinckney 2008, Lawrenz & Smith 2013), some studies showed that, abiotic agents have a greater impact on phytoplankton diversity and their biomass (Tirok & Gaedke 2007, Schabhüttl *et al*. 2013, Rasconi *et al*. 2017). In the other words, climatic conditions can be regarded as important factors affecting phytoplankton communities; hence, the effect of some meteorological factors on the frequency of dominant taxa was also studied in this research. In the present study, among several meteorological factors, air temperature variables look more impressive than the others while the dependence of different taxa to this factor was not similar. As an example, most green algae showed a significant dependence to temperature variables; but in diatoms, the influence of temperature was not significant. According to the results of present study and the model achieved for the genus *Tetraedron* (Chlorophyta), temperature variables such as T_{min}, T_{max}, and T_{dry} had major role in cell number of this genus in phytoplankton communities. But in the model achieved for genus *Nitzschia* (Bacillariophyta), dependence to temperature variables was not serious and significant. It seems that, temperature variables did not have significant effect on cell proliferation and cell number of *Nitzschia* throughout the seasons.

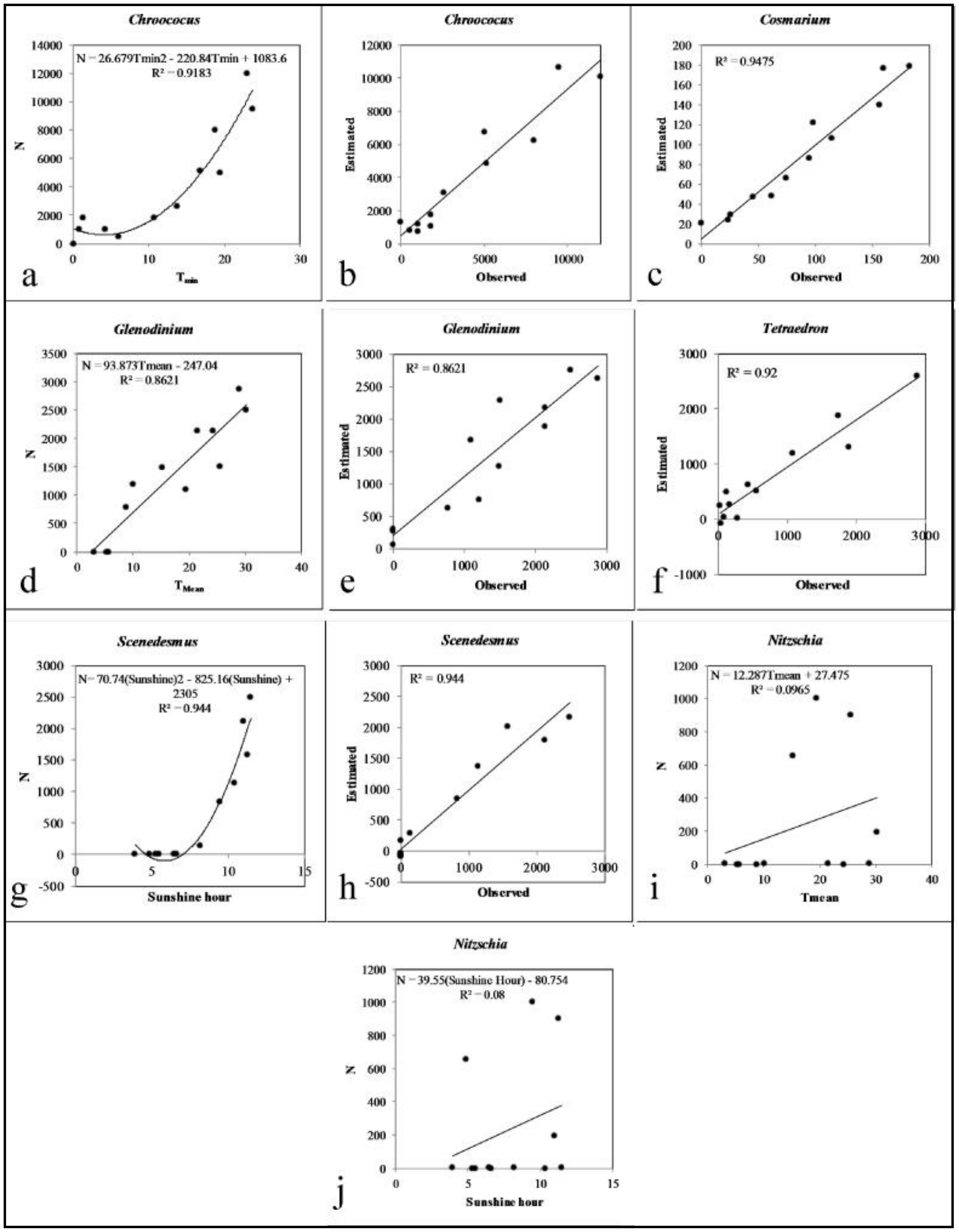

Fig. 4. Scatter plot of algal density versus meteorological variables and observed-estimated values charts.

Previous studies have also emphasized on the temperature dependence of green algae (Gómez & González 2005, Guo *et al*. 2015). It should be noted that, according to the results of present study, the sensitivity of several green algae to the temperature variables was not similar. For example, the equation achieved for *Tetraedron* (N=3835–1606T_{min}+738(S)–2324T_{max}+4008T_{dry}) showed significant correlation between cell number of algae and most of the temperature variables (T_{min}, T_{max}, and T_{dry}). Therefore, it can be concluded that, temperature is the most important factor in determination of this genus abundance. On the contrary, in the equation achieved for *Cosmarium* (N=–4.7+10.4 (S)+7.38T_{dew}), the cell number showed correlation with only one temperature variable (T_{dew}); or in *Scenedesmus*, thermal variables were not determining factors in algal cell density (N=70.74(S)^2–825.16(S)+2305), and sunshine hour was determinative climatic variable.

However, in some of the previous studies, the optimal range of temperature for green algae was reported as 20–27 °C. The results of the present study and the abundance of green algae in the warm seasons of the year, confirm these reports. Similar to green algae, *Glenodinium* (Pyrrhophyta) exhibited strong dependence on temperature variables. In this genus, T_{mean} seems to be an influential factor (N=93.873T_{mean}–247.04). In one of the previous studies, Grigorszky *et al*. (2003) reported temperature as an important factor to control dinoflagellates occurrence. The range of 12–26 °C was reported as the proper temperature for this group of phytoplankton. The results of the current study also showed that, maximum population density of this genus is observed in the warm months of the year. The evidences obtained from present study also indicate a positive correlation between temperature and cellular density of dinoflagellates such as *Glenodinium*.

Unlike Chlorophyta and Pyrrhophyta, reports about diatoms do not indicate a clear trend in dependence of diatoms growth on air temperature. In the other word, some diatoms have a narrow temperature range while others are able to withstand in wide temperature ranges (Burnett *et al*. 1977). In contrary, some studies expressed the sensitivity of the diatoms to high temperatures. For instance, Atkinson (1995) indicated that, cell size of diatoms decreases with increase of temperature. In the other study, the wide range of temperature (5–20 °C) was reported for optimum growth of *Thalassiosira corviceriata* (Popovich & Gayoso 1999). In the present study, a wide range of temperature resistance was also observed in diatoms and their populations. In the other words, in the equation achieved for *Nitzschia* as a dominant genus of diatoms in studied sites (N=12.287T_{mean}+27.475), the cell number showed very little correlation to temperature variables so that, T_{mean} was the only effective factor associated with this algae abundance. It is necessary to mention that, the coefficient of this equation was very low (0.096 and 0.08, respectively).

As general conclusion, authors believe that, temperature is an environmental factor which plays an important role in development of algal communities, whose effect varies from one taxon to another. Due to the impact of temperature on enzymatic reactions of living organisms, this environmental factor affects many critical biological mechanisms such as photosynthesis, respiration and cell division. In addition to the cell biological mechanisms, temperature can also affect species diversity of algae in aquatic ecosystems (Odum *et al*. 1995). The importance of temperature in development of phytoplankton communities and their biological activities has motivated many researchers to provide mathematical formulas to show the correlation between temperature, light intensity and phytoplankton dynamics in aquatic ecosystems (Eppley 1972, Lehman *et al*. 1975, Geider *et al*. 1997). The mathematical formulas achieved in the present study also showed that, temperature variables are the key factors which can affect most phytoplanktons occurrence (Table 3).

Likewise, light is another environmental factor and considered as a basic requirement of photosynthetic organisms like phytoplanktons. Light tolerance is different in several groups of algae. For example, Chlorophyta are resistant to high intensities of light while Rhodophyta adapt well with lower light intensity. Even some algal groups such as Bacillariophyta show very little sensitivity to light intensity. In the present study, positive correlation of light density and cell number of Chlorophyta such as *Scenedesmus*, *Cosmarium*, and *Tetraedron* was observed (Table 3). Results derived from the present study also showed the low sensitivity of diatoms to light density ($N=12.287T_{mean}+27.475$). One of the reasons can be attributed to constitute presence of diatoms in several seasons as well as presence of Chlorophyta in seasons such as spring and summer is different light instability. For example, the cell density of *Scenedesmus* as a green algae showed significant correlation with sunshine hour ($N=70.74(S)^2–825.16(S)+2305$). This correlation was also observed in equations achieved for other studied green algae. So that, in these taxa (*Cosmarium*, and *Tetraedron*), cellular density was correlated with temperature and radiation simultaneously (Table 3). The equations achieved for *Cosmarium* ($N=–4.7+10.4(S)+7.38T_{dew}$), as well as *Tetraedron* ($N=3835–1606T_{min}+738(S)–2324T_{max}+4008T_{dry}$), exactly indicated these correlations. The importance of light intensity in the formation of phytoplankton communities has led many researchers to provide mathematical formulas describing the correlation between intensity of phytoplankton communities and light intensity (Carlos *et al*. 1999, Lonin & Tuchkovenko 2001). The mathematical models achieved in the present research showed that, the cell numbers of Chlorophyta (*Scenedesmus*, *Cosmarium*, and *Tetrahedron*) are the functions of solar radiation intensity.

The models obtained in this study also showed that, the regression equation for each taxon is different. *Chroococcus* was a parabolic function of minimum temperature (T_{min}), and *Glenodinium* had a linear relationship with average air temperature (T_{mean}). *Nitzschia* had no significant correlation with any meteorological variables. *Scenedesmus* population also was a parabolic function of sunshine hour (S) and the other two species, *Cosmarium*, and *Tetraedron* were multilinear functions of bright sunshine (S) and temperature variables consist of dry temperature (T_{dry}), dew point temperature (T_{dew}), and maximum and minimum temperatures (T_{max}, and T_{min}).

In a general conclusion, this study shows a significant increase in total diversity and abundance of photosynthetic taxa in the warm seasons of the year. In the other words, the cell number of dominant taxa can be changed in aquatic ecosystems by seasonal shift but the sensitivity of several taxa to seasonal changes was not the same. The changes observed in the abundance and dominance of phytoplankton taxa throughout the seasons which can be affected by environmental factors such as temperature and radiation intensity. These factors are among the most important environmental factors affecting the growth rate of algae.

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