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Ecological and Statistical Evaluation of Algal Flora and Water Quality of Karasu Stream

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ABSTRACT: The ecological and statistical evaluation of algal flora and water quality in Karasu Stream (Sinop, Turkey) were investigated from May of 2013 to April of 2014. A total of 70 taxa were identified, including Cyanophyta, Bacillariophyta, Charophyta, Chlorophyta, Dinoflagellata and Euglenozoa. The Bacillariophyta was dominant taxa in terms of both population density and number of species in the stream. It was followed by Chlorophyta, which was important in the phytoplankton at the end of the summer, autumn and the early winter. The positive correlations between Bacillariophyta with pH and nitrate; Chlorophyta with conductivity and silica; Cyanobacteria with conductivity, organic matter and nitrate; Charophyta with temperature and pH; Euglenozoa with total hardness were determined. Temperature was strongly positively correlated with pH and organic matter while dissolved oxygen was strongly negatively correlated with organic matter. Results indicated that the water was in the category of hard and moderately hard water; moderately polluted and sustaned slightly alkaline character.
Keywords: Diversity, MDS, phytoplankton, Karasu Stream, water quality

Karasu Çayı Alg Florası ve Su Kalitesi Üzerine Ekolojik ve İstatistik Bir Değerlendirme

ÖZET: Karasu Çayı'nın (Sinop, Türkiye) alg florası, su kalitesinin ekolojik ve istatistiksel değerlendirmesi Nisan 2014 Mayıs 2013 tarihleri arasında çalışılmıştır. Cyanophyta, Bacillariophyta, Charophyta, Chlorophyta, Dinoflagellata ve Euglenozoa divizyolarına ait toplam 70 takson tespit edilmiştir. Bacillariophyta divizyosu hem tür sayısı hem de populasyon yoğunluğu bakımından baskın olmuştur. Daha sonra Chlorophyta divizyosu yaz ve sonbahar sonu ile kış başında fitoplanktonda önemli olmuştur. Bacillariophyta, pH ve nitrat ile, Chlorophyta iletkenlik ve silis ile, Cyanobacteria iletkenlik, organik madde ve nitrat ile, Charophyta sıcaklık ve pH ile, Euglenozoa toplam sertlik ile pozitif yönde korelasyona sahiptir. Sıcaklık ile pH ve organik madde arasında pozitif yönde kuvvetli korelasyon, çözünmüş oksijen ve organik madde arasında ise negatif yönde kuvvetli korelasyon tespit edilmiştir. Analiz sonuçlarına göre Karasu Çayı'nın suyu orta sert ve sert sular kategorisinde yer almakta olup, orta derecede kirli ve hafif alkalin karakterdedir.
Anahtar Kelimeler: Çeşitlilik, MDS, fitoplankton, Karasu Çayı, su kalitesi

INTRODUCTION

Rivers play a key role in maintaining ecosystem balances through transporting and from long residence time water bodies with natural and chemical filtering processes before reaching the oceans (Hamilton et al., 2012). Successful river ecosystem management requires an understanding of the environmental variables controlling a high quality food source such as phytoplankton (Ruse and Love, 1997). It was stated that few studies on rivers are available (Roth, 2009). The reason for the smaller number of studies is because of irregular water volume of the river, the absence of the appropriate arms for periodic studies and the difficulty of sampling. River water quality is a key factor for the functionality of rivers as ecosystems. Global change might compromise these functions by altering climatic conditions and modified land use (Fischlin et al., 2007).

Multivariate analysis has been used to identify the environmental variables that are most correlated with variation in the composition of the phytoplankton assemblage (Ruse and Love, 1997). The Shannon-Wiener index (Shannon-Wiener, 1949) is calculated in order to determine the changes in the population structure. Multi-dimensional scaling (MDS) shows points, which represent samples that are very similar in composition (Clarke and Warwick, 2001). The feature of MDS plots is the ability to superimpose, onto the biotic MDS, the value of a further variable, as circles of different size. Its purpose is to represent the samples as points in low-dimensional space. Points that are close together represent samples that are very similar in species composition, however, points that are far apart correspond to very different communities. Bubble plots were represented the values of this variable as a symbol of differing sizes and superimposing these symbols on the biotic ordination of the corresponding samples (Clarke and Warwick, 2001). The MDS stress values are close to zero (0.1=fair; 0.08=good) (Kalaycı, 2006).

Main objective of this study was to investigate the ecological and statistical evaluation of algal flora and water quality properties in the stream. Other objectives were to determine the effects of physicochemical parameters on the distributions of phytoplankton divisions and to determine the ecological conditions of stream and provide some data for regarding other other ecological parameters.

MATERIALS and METHODS

Turkey maintain rich resources of inland waters, contain 26 river basins with different precipitation regimes for each. Therefore, flow capacities of each of these basins are different from each other. The total water potential in the river basin is 186.05 billion m^3 in Turkey. Among the Turkey's river basins, Sinop ranked in no 13^{th} in the Western Black Sea Basin and industry and urbanization rate in it is slightly lower than those the other watersheds in the basin (Akın and Akın, 2007). Karasu Stream is located in Sinop and is born in Gündüzlü Forest in the Küre Mountains. The stream is largely fed by groundwater. Its total length is 80 km and fall into the Black Sea to the west of Sinop. The stream basin is made of alluvial material. Melting snow and continuous rainfall during the spring increases its stream flow. The width of the stream is changed seasonally and flows in a narrow channel (OSİB, 2012).

Samples were collected monthly, from four stations from May of 2013 to April of 2014 (Fig. 1). Samples were preserved in formaldehyde to provide final concentration as 4%. Phytoplankton counting and identification were done by following Utermöhl's method (Sournia, 1978) using an inverted microscope (Micros Austria, MCXI600) and LEICA DM500 model light microscope.

Conductivity (Con), pH, temperature (T), dissolved oxygen (DO) and redox potential (ORP) were measured with the portable digital Hach Lange, HQ40D sampling equipment. Nitrite (NO_2), ammonia (NH_3), total hardness (TH), phosphorus (P) and organic matter (OM) analysis were performed based on the standard methods (Apha, Awwa, Wef 2005). Silica (Si) and nitrate (NO_3) analysis were conducted by the Merck kits.

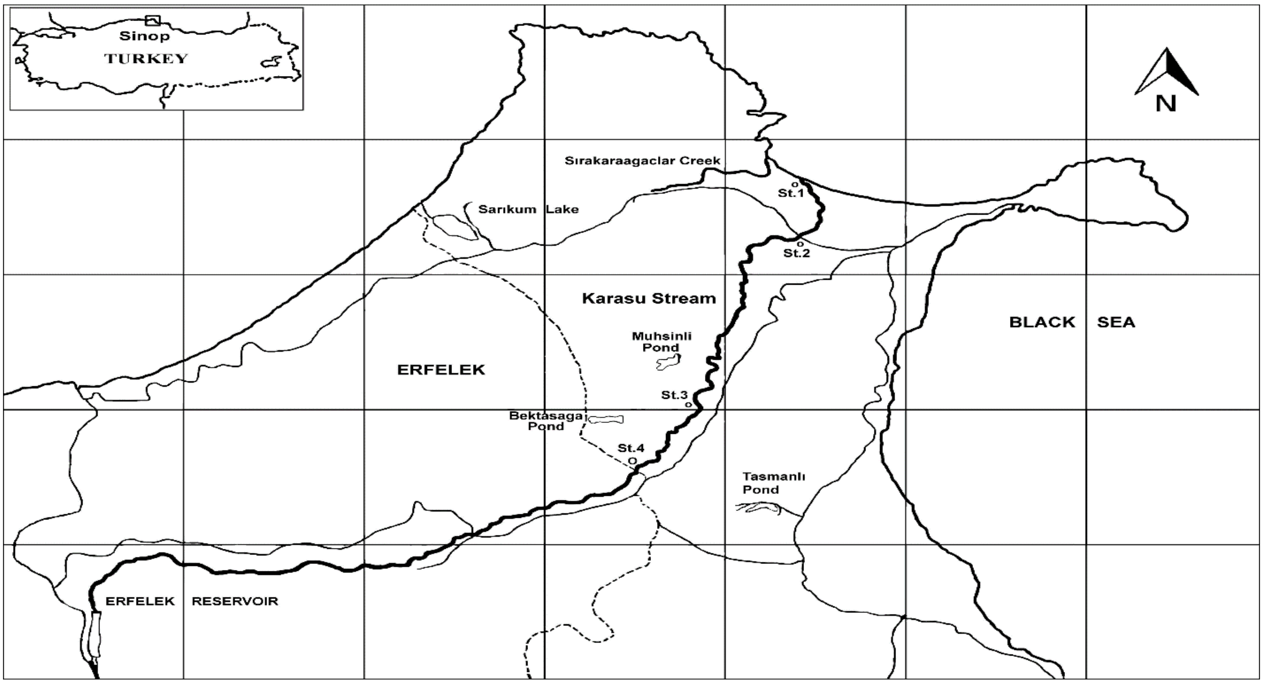

Figure. 1. The geographical location of Karasu Stream and sampling stations.

The studies by Anagnostidis and Komárek (1988), Komárek and Anagnostidis (1986, 1989, 1999), Hartley (1996), Krammer and Lange-Bertalot (1991a, 1991b, 1999a, 1999b), John et al. (2003), Wehr and Sheath (2003), Krammer (2003) and Tsarenko et al. (2006). were used to identify algae. Systematic arrangement was made in accordance with the AlgaeBase database (Guiry and Guiry, 2016).

The Shannon-Wiener index (H') was applied to the species abundance data. Biotic multi-dimensional scaling (MDS) was performed for environmental variables and divisions data (Clarke and Warwick, 2001) on the stations throughout the year. It was used to determine similarity measures with normalized Euclidean distance for environmental variables and Bray-Curtis similarity for abundance data. Draftsman plot analyses were applied to all data to determine correlation. These analyses were carried out with Primer 5.0 (Clarke and Warwick, 2001). The descriptive statistics of physicochemical parameters were done with SPSS Statistics 21.

RESULTS

A total of 70 taxa were identified, including 5 Cyanophyta, 44 Bacillariophyta, 1 Charophyta, 16 Chlorophyta, 3 Dinoflagellata and 1 Euglenozoa. The list of taxa identified in Karasu Stream and its frequency values were presented in Table 1. The maximum, minimum, mean values and standard deviation of physicochemical parameters were given in Table 2 for all stations.

Table 1. The list of algal taxa identified in Karasu Stream and its frequency values (100-81% continuous current, 80-61% existing mostly, 60-41% often present, 40-21% sometimes present and 20-1% rarely found).

TAXA	St. 1	St. 2	St. 3	St. 4
CYANOBACTERIA				
Aphanothece microscopica Nägeli	8			
Chroococcus minutus (Kützing) Nägeli	8			
Chroococcus turgidus (Kützing) Nägeli	8	8		8
Merismopedia punctata Meyen	8			
Microcystis aeruginosa (Kützing) Kützing	17		8	17
BACILLARIOPHYTA				
Achnanthes ventralis (Krasske) Lange-Bertalot	42	58	75	42
Bacillaria paxillifera (O.F.Müller) T.Marsson	25	25	17	
Craticula cuspidata (Kutzing) D.G.Mann	17	8	17	25
Craticula submolesta (Hustedt) Lange-Bertalot	33	58	58	42
Cyclotella cyclopuncta Håkansson and J.R.Carter	75	67	58	58
Cyclotella praetermissa Lund	33	33	25	25
Cymbella affinis Kützing	67	83	100	58
Cymbella helvetica Kützing			8	
Cymbopleura hybrida (Grunow ex Cleve) Krammer		8		
Diatoma vulgaris Bory de Saint-Vincent			25	17
Epithemia argus (Ehrenberg) Kützing		8		
Fallacia pygmaea (Kützing) A.J.Stickle and D.G.Mann		8		
Fragilariforma virescens (Ralfs) D.M.Williams and Round	67	92	100	67
Gomphonema angustatum (Kützing) Rabenhorst	42	8	8	
Gomphonema angustum C.Agardh	8			
Gomphonema olivaceum (Hornemann) Brébisson	50	25	58	33
Gomphonema truncatum Ehrenberg	8	25	25	8
Gyrosigma acuminatum (Kützing) Rabenhorst	8	33		
Hantzschia amphioxys (Ehrenberg) Grunow	8			
Meridion circulare (Greville) C.Agardh	50	75	83	75
Navicula radiosa Kützing			8	
Navicula tenuipunctata Hustedt			25	8
Nitzschia brevissima Grunow	8			
Nitzschia flexa Schumann	25	17	8	
Nitzschia sigma (Kützing) W.Smith		8		
Nitzschia sigmoidea (Nitzsch) W.Smith		8		
Nitzschia sociabilis Hustedt	8			
Nitzschia tryblionella Hantzsch	8	17	25	
Parlibellus crucicula (W.Smith) Witkowski, Lange-Bertalot & Metzeltin	33	33	25	25
Pinnularia intermedia (Lagerstedt) Cleve	8		17	
Pinnularia microstauron (Ehrenberg) Cleve	8	17		
Pinnularia viridis (Nitzsch) Ehrenberg			8	
Rhoicosphenia abbreviata (C.Agardh) Lange-Bertalot		8		
Rhopalodia gibba (Ehrenberg) Otto Müller		8	25	
Rhopalodia gibberula (Ehrenberg) Otto Müller			17	8
Rhopalodia rupestris (W. Smith) Krammer	8	8		
Sellaphora pupula (Kützing) Mereschkovsky			8	
Staurosira venter (Ehrenberg) Cleve and Moeller	8	8	42	50
Staurosirella leptostauron (Ehrenberg) D.M.Williams and Round	8			
Surirella linearis W.Smith	8			
Surirella minuta Brébisson	25	50	17	25
Synedra ulna (Nitzsch) Ehrenberg	25	42	33	33
Tabularia fasciculata (C.Agardh) D.M.Williams and Round	92	83	83	42
Ulnaria ulna (Nitzsch) P.Compère	8	17		
Cosmarium bioculatum Brébisson ex Ralfs	8	25	17	8

CHLOROPHYTA				
Ankistrodesmus falcatus (Corda) Ralfs	17	17	17	8
Asterococcus limneticus G.M.Smith	8			
Chaetophora attenuata Hazen	8			
Chlamydomonas reinhardtii P.A.Dangeard	8	8	8	
Crucigenia tetrapedia (Kirchner) Kuntze	8	8		
Desmococcus olivaceus (Persoon ex Acharius) J.R.Laundon		8		
Gloeotila scopulina (Hazen) Heering	8			
Gloeotila subconstricta (G.S.West) Printz	8	17		
Kirchneriella lunaris (Kirchner) K.Möbius			8	
Micractinium pusillum Fresenius	8			
Monoraphidium mirabile (West and G.S.West) Pankow		17		
Monoraphidium obtusum (Korshikov) Komárková-Legnerová		8		
Scenedesmus quadricauda (Turpin) Brébisson	8	8		
Stauridium privum (Printz) Hegewald	8			
Ulothrix tenerrima (Kützing) Kützing		17	8	
Westellopsis linearis (G.M.Smith) C.-C.Jao	8			
DINOPHYTA				
Ceratium hirundinella (O.F.Müller) Dujardin				8
Ceratium furcoides (Levander) Langhans	8			
Chimonodinium lomnickii (Woloszynska) S.C. Craveiro, A.J.Calado, N.Daugbjerg, Gert Hansen and Ø.Moestrup	8			
EUGLENOZOA				
Euglena gracilis Klebs	17		8	17

Table 2. The descriptive statistics of the physicochemical parameters in water of Karasu Stream.

		T (°C)	DO (mgL^{-1})	Con (μScm^{-1})	ORP (mV)	pH	NH_3 (mgL^{-1})	NO_2 (mgL^{-1})	NO_3 (mgL^{-1})	P (mgL^{-1})	TH (°FS)	OM (mgL^{-1})	Si (mgL^{-1})
St. 1	**Min.**	9	5	383	119	6	29	0.002	0.000	0	28	2	2
	Max.	30	10	894	275	8	395	0.044	0.066	3	48	10	4
	Mean	18	8	545	168	7	239	0.013	0.018	1	35	5	3
	S.D.	6	1	124	37	0	124	0.012	0.018	1	6	2	1
St. 2	**Min.**	9	7	367	133	7	11	0.000	0.000	0	19	1	2
	Max.	28	10	559	301	8	237	0.041	0.045	3	50	9	5
	Mean	18	9	495	184	7	80	0.008	0.013	1	32	4	3
	S.D.	6	1	51	45	0	58	0.011	0.014	1	7	2	1
St. 3	**Min.**	7	8	305	132	6	8	0.000	0.000	0	8	1	2
	Max.	28	12	478	273	8	163	0.010	0.060	3	48	7	3
	Mean	17	10	401	159	8	60	0.002	0.015	1	26	4	3
	S.D.	6	1	48	38	1	44	0.004	0.019	1	10	2	1
St. 4	**Min.**	7	8	296	112	7	15	0.000	0.000	0	15	1	2
	Max.	28	11	445	195	8	911	0.035	0.037	5	44	7	3
	Mean	18	9	361	145	7	272	0.007	0.013	1	25	4	3
	S.D.	7	1	40	24	1	310	0.013	0.015	1	7	2	1

The seasonal variations of Shannon-Wiener diversity index (H'), total species number (S), total organism (N, in the seconder axis) were given in Fig. 2. MDS bubble plot configuration for environmental variables and division abundance data were presented in Fig. 3 and Fig. 4, respectively.

In this study, draftsman plot analyses, among the physicochemical properties results show that temperature and dissolved oxygen were strongly negatively correlated (-0.856), however, temperature and pH (0.542) and temperature and organic matter (0.768) were strongly positively correlated. Also, dissolved oxygen and organic matter were strongly negatively correlated (-0.723); conductivity and nitrate were positively correlated (0.617). Finally, it is revealed that ammonia and phosphorus in this study were positively correlated (0.566).

The correlations were determined between Cyanobacteria and each of conductivity (0.676), organic matter (0.542) and nitrate (0.482). Charophyta was positively correlated with temperature (0.490), with pH (0.438), with the total number of organism (0.265). However it was negatively correlated with dissolved oxygen (-0.476). Chlorophyta was correlated with dissolved oxygen (-0.444), with conductivity (0.436), with Si (0.415) and with the total number of organism (0.254). Dinophyta was correlated with ORP (-0.081) with temperature (-0.070) and with the total number of organism (-0.085).

Euglenozoa was correlated with total hardness (0.390), with conductivity (-0.132) and with the total number of organism (0.047). Bacillariophyta was correlated with pH (0.447), with phosphorus (-0.296), with nitrate (0.211) and with the total number of

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organism (0.984).

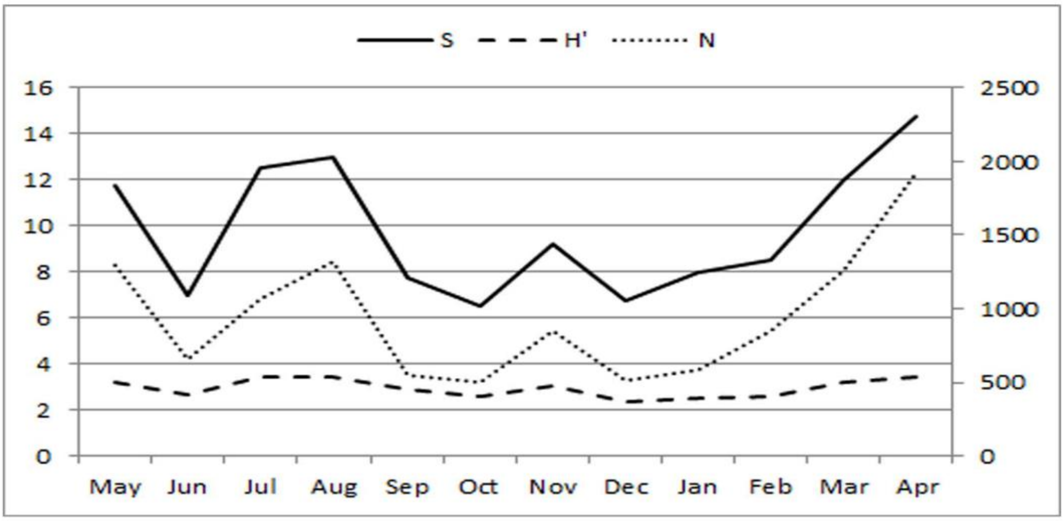

Figure. 2. The seasonal variation of Shannon-Wiever diversity index H' (log_2), S total species number (S), total organism (N, in the seconder axis).

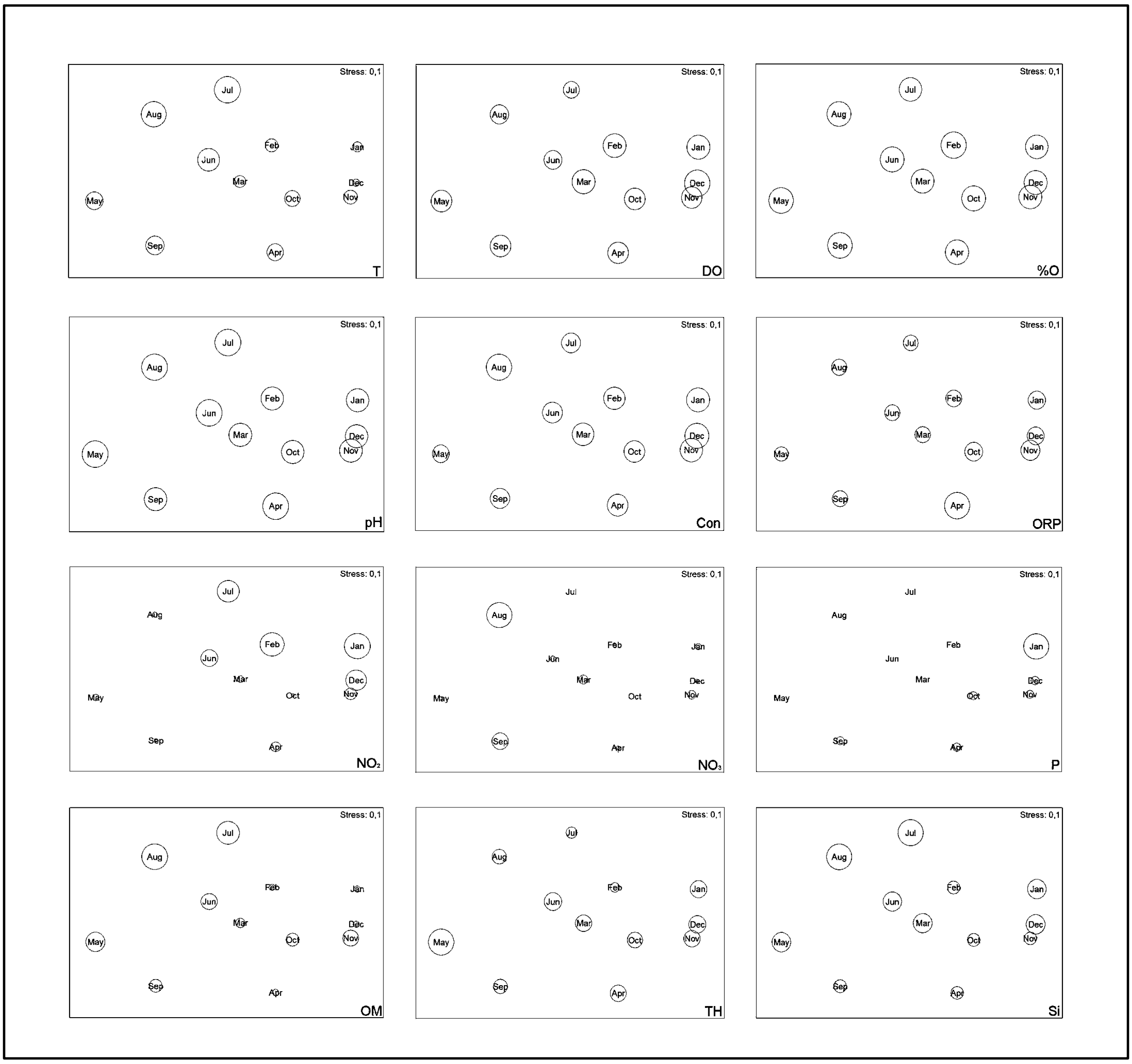

Figure. 3. MDS bubble plots for environmental variables.

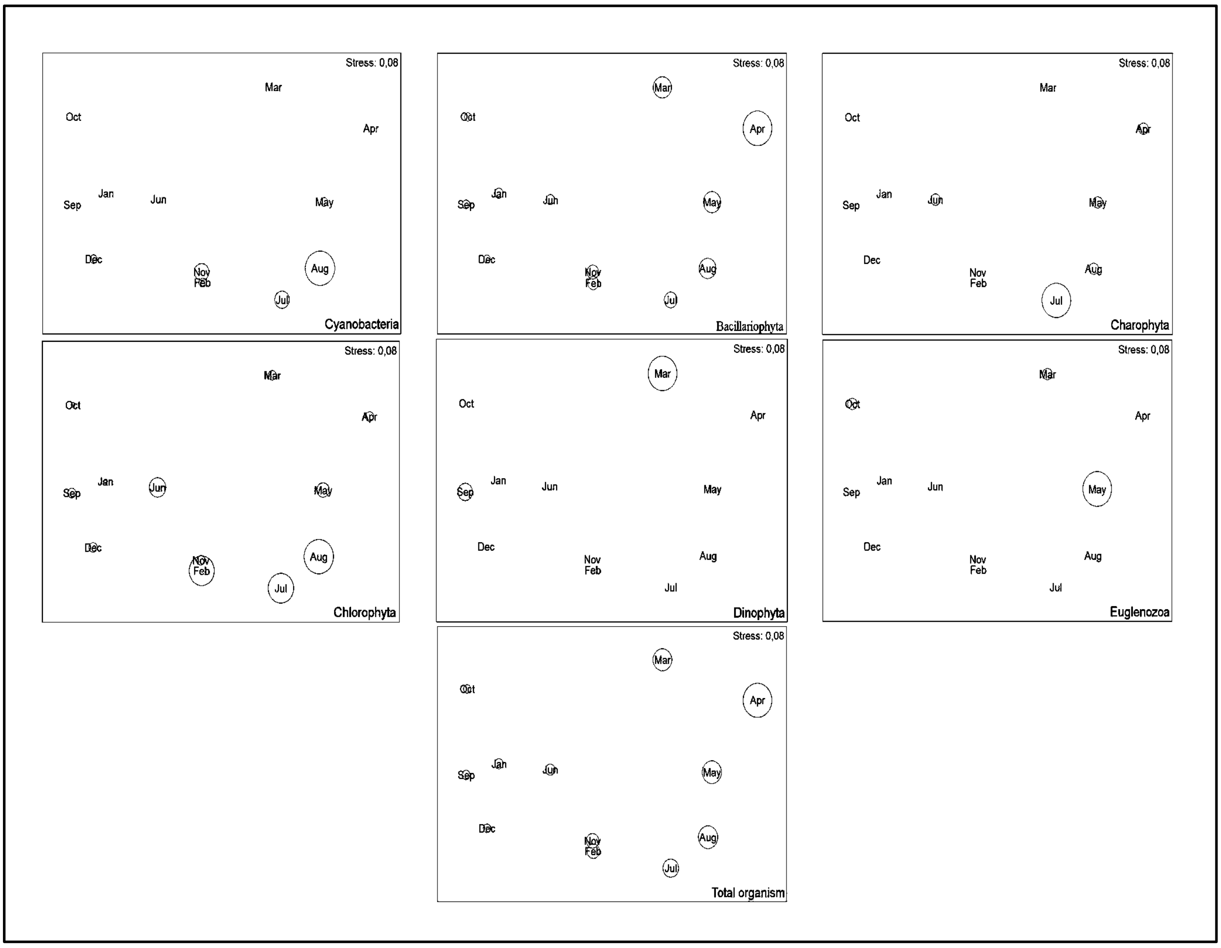

Figure. 4. MDS bubble plots for division abundance data.

DISCUSSION

Over the course of the study, the water temperature was recorded between 7°C (December, St. 3-4) and 30°C (July, St. 1). Water temperature is one of the most important parameters for water quality and ecosystem studies because it influences many chemical and biological processes (Larnier et al., 2010). The minimum dissolved oxygen value was found as 5 mg L^{-1} (July, St. 1) and the maximum value was measured as 12 mg L^{-1} (February and December, St. 3). Dissolved oxygen is essential for a healthy aquatic ecosystem. The amount of oxygen that dissolves in water can vary with daily and seasonal patterns and decreases with higher temperature, salinity and elevation (Wetzel, 2001). The conductivity was changed between 296 µS cm^{-1} (July, St. 4) and 894 µS cm^{-1} (August, St. 1). The maximum value might be related to St.1's closeness to the sea. Conductivity generally ranged between 10 and 1.000 µS cm^{-1} in most rivers or lakes that have outflows. The pH varied from 6 to 8 in the stream water, so the stream water sustained slightly alkaline character. The observed pH values were within the range (6.5-9.0) to permit all natural processes of aquatic life (USEPA, 2009). Redox potential was measured from 112 mV (St. 4, November) to 301 mV (St. 2, November). Life is powered by redox reactions, chemical processes in which electrons are transferred from one molecule to another, with the release of energy. The aerobic condition, characterized by the highest redox potential, occurs when there is an abundance of oxygen and the relative absence of organic matter owing to toxic sewage wastes and the decomposition of organic matter near the surface of well-aerated soils (Anonymous, 2014). Nitrite was ranged from 0 to 0.044 mg L^{-1} while nitrate was ranged from 0 to 0,066 mg L^{-1} during the study. Horne and Goldman (1997) reported that nitrite is in very low quantities in natural waters because it converts into nitrate in the presence of oxygen. The lowest total hardness value was measured as 8 °FS at St. 3 in February, while the highest value was 50 °FS at St. 2 in May. According to the mean hardness values (25-35 °FS), the water was in the category of hard and moderately hard water. The mean value of silica was measured as 3 mg L^{-1}. Silica is the most abundant element on earth after oxygen and rivers transport large amounts of it to the sea. Rivers generally contain 4 mg L^{-1} silica (Lenntech, 2014). Phosphorus values were ranged of 0-5 mg L^{-1}. The maximum value was determined at St. 4 in January.

According to the USEPA (1986) the limit value was 1 mg L^{-1} for rivers / streams. The maximum value may be due to the mixture of sewage to the stations. According to the OECD (1982) criteria, the stream water had oligotrophic character. Organic matter was changed between 1 mg L^{-1} and 10 mg L^{-1} and ammonia values were changed between 8 mg L^{-1} and 911 mg L^{-1}.

According to the MDS bubble plots for environmental variables, temperature changed seasonally. Dissolved oxygen showed an inverse proportion with temperature. pH decreased in winter and conductivity increased in August. Redox potential increased in April, but did not change in remaining times. Nitrite increased in summer and winter, decreased in August whereas nitrate increased in August. Phosphorus was important in January when organic matter was important in summer, early autumn and spring and total hardness was not important in July and February, silica was important in summer and winter.

According to the MDS bubble plots for division data, Cyanobacteria was most important in August and late November, July and May. When the distribution of the division at stations was examined, it was found mostly at St. 1 and next St. 4, St. 3 and St. 2. Charophyta was increased in July, May, August and April, respectively. Additionaly Charophyta was outnumbered at St. 2 and later St. 3, St. 1 and St. 4. Chlorophyta was important at the end of the summer, autumn and the early winter. The highest amount of Chlorophyta was found at St. 1 and then at St. 2, St. 3 and St. 4 in decreasing amounts. Dinophyta was detected in March and September. It was found at St. 1 and then St. 4. Euglenozoa was recorded mostly in May and late October and March. It was important at St.1 and after St. 4 and St. 3. Bacillariophyta was found all the year, also especially important in April and later March, May, August and July. Bacillariophyta was found mostly at St. 3, St. 2, St. 4 and St. 1., respectively. Besides total organism was most important April, August, May, March, July, November and February.

According to the Shannon-Wiener index, the maximum index value was 3.4 in August and April. The minimum index value was 2.3 in December, because in this month no species were in St. 4. According to the diversity results for mean values (H'=2.2), stream water was found moderately polluted (Wilhm and Dorris, 1968).

The number of total organism changed between 1917 org mL^{-1} (April) and 497 org mL^{-1} (October) over the study period. Bacillariophyta affected the total organism number and was dominant in April with 1864 org mL^{-1} and in March with 1172 org mL^{-1} and in May with 1154 org mL^{-1}. The minimum number of Bacillariophyta was 462 org mL^{-1} in October and December. Especially *Cymbella affinis* than *Fragilaria virescent*, *Meridion circulare* and *Tabularia fasciculata* were important in phytoplankton. *Cymbella affinis* with 58-100%, *Fragilariaforma virescens* with 67-100%, *Cyclotella* spp. with 25-75%, *Gomphonema* spp. with 8-58%, *Navicula* spp. with 8-33%, *Nitzschia* spp. with 8-25%, *Pinnularia* spp. with 8-17%, *Rhopalodia* spp. with 8-25%, *Surirella* spp. with 8-50% were found in frequency values. It was concluded that Bacillariophyta sustained highest number of organisms and species diversity in stream studies in our country (Arslan and Gönülol, 1992; Altuner and Pabuççu, 1996; Ertan and Morkoyunlu, 1998; Kara and Şahin, 2001; Dere et al., 2002; Şahin, 2003; Çiçek et al., 2010; Baykal et al., 2011).

Cyanobacteria was found 71 org mL^{-1} in August, then 36 org mL^{-1} in July and November. The species of Cyanobacteria have frequency values between 8% and 17%. Chlorophyta was 124 org mL^{-1} in August and107 org mL^{-1} in July and February. Chlorophyta was comprised of species varying between 8-17% frequencies. Charophyta was determined as 53 org mL^{-1} in July and represented by one species changing between 8% and 25% frequency values. Dinophyta was 36 org mL^{-1} in March and the species of Dinophyta was represented 8% frequency. Euglenozoa was found 53 org mL^{-1} in May. Euglenophyta was represented by one species and had 8-17% frequency values. Total frequencies of algae in the each station were detected. It is observed that the first station with 73%, second station with 60%, third station with 53% and fourth station with 34% had frequency values. The reason for the decrease in frequency values towards St. 4 may be due to a decrease in the flow rate towards St. 1.

In conclusion succession of organisms varied seasonally and Bacillariophyta was dominant and affect total biomass and was available all year long. Chlorophyta was important in the phytoplankton at the end of the summer, autumn and the early winter. In addition, environmental variables had similar changes seasonally. Temperature was strongly positively correlated with pH and organic matter. The dissolved oxygen and organic matter were strongly negatively correlated. Analyses results showed that the water was in the category of hard and moderately hard water, it was moderately polluted and it had slightly alkaline character.

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