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Determination of trophic weight and indicator values of diatoms in Turkish running waters for water quality assessment

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Abstract: This study, the first such attempt in Turkey, aimed to investigate the distribution of diatom species related to the variation of total phosphorus (TP) in eight basins to determine trophic weight and indicator values of diatom species and to develop the Trophic Index-Turkey (TIT) for assessing the ecological status of freshwaters. The distribution of the diatom species in 225 running water bodies from 8 basins of Turkey was determined in 2014 (summer and fall) and 2015 (spring and summer) in association with TP variation. Trophic values for 219 species were determined during this study and many of these are presented for the first time. Optima and tolerance TP values were calculated for each species in the different aquatic ecosystems using weighted average regression. Diatom species such as *Clevamphora ovalis*, *Caloneis amphisbaena*, *Gyrosigma acuminatum*, *Navicula tripunctata*, and *Nitzschia umbonata* showed high trophic weight values, while *Achnanthidium minutissimum*, *Cymbella excisa*, *Didymosphenia geminata*, *Hannaea arcus*, and *Meridion circulare* had low trophic weight values. These findings provide supplementary information about the biotic integrity of the water bodies and could be used to develop the TIT for the bioassessment of freshwater ecosystems, especially running water bodies.

Key words: Diatom, ecological status, freshwater, indication system, trophic weight

1. Introduction

Evaluating the ecological status of water bodies based on physical and chemical variables of the ecosystems is one of the relevant approaches in water quality assessment. The use of physical and chemical properties of water to assess water quality gives a good impression of the status, productivity, and sustainability of a water body (Mustapha, 2008). However, this method with instantaneous measurements mainly gives restricted knowledge of water conditions. The chemistry at any sampling time is a snapshot of the water quality, which ignores the temporal variation of water quality variables in aquatic ecosystems (Rocha, 1992). On the other hand, the use of biological monitoring provides a direct measure of ecological integrity by using the response of biota to the changes in environmental variables (Karr, 1991; EC, 2009).

The European Water Framework Directive has required different biological quality elements (phytobenthos, phytoplankton, macrophytes, benthic invertebrates, and fish) to be used for assessing the ecological quality of water bodies since 2000 (EC, 2009). Diatoms are a major group of phytobenthos (Della Bella et al., 2007; Bennion et al., 2014) and can be sampled at times of the year from almost all aquatic habitats. Diatoms are an extremely diverse group of algae with 100,000 species (Round, 1991). Diatom assemblages in various habitats respond rapidly and sensitively to environmental change and are ideal ecological indicators of water bodies (Pan and Stevenson, 1996; Kelly et al., 1998; Potapova and Charles, 2003; Rimet et al., 2007; Delgado and Pardo, 2014). The use of benthic diatoms for the assessment of water quality conditions is not a new issue and has been used since the 1900s (Kolkwitz and Marsson, 1908). These organisms are being used to assess the ecological integrity of running waters around the world (e.g., Kelly et al., 1998; Rott et al., 1999, 2003; Potapova et al., 2004; Della Bella et al., 2007; Taylor et al., 2007).

Changes in sensitive and tolerant taxa enable a more accurate indication of changes in biological conditions, such as a loss of sensitive species or an increase in nonnative species (Rocha, 1992; Davies and Jackson, 2006). The relationship between diatoms and environmental variables is strong and quantifiable, making diatoms appropriate quantitative indicators of ecological conditions in aquatic ecosystems (Pan and Stevenson, 1996; Oliveira et al., 2001). A solid correlation between diatom community

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composition, total nitrogen, and total phosphorus has been demonstrated. Hydromorphological alterations affect a whole scale of ecological conditions by changing water retention, water current, turbidity, substrate heterogeneity, and riparian structure, which contribute to changes in nutrient and organic matter cycle (Moss, 2008; Cron et al., 2015).

The use of diatom assemblages as reliable indicators of changes in environmental conditions is deciphering integrated environmental information with species richness due to their presence or absence in ecosystems (Pan and Stevenson, 1996) and linkage in biogeochemical cycles. The gathered information on occurring taxa is used in various biological metrics to classify the water quality classes (Karr and Chu, 1999; Rott et al., 1999; Dell'Uomo, 2004; Kelly et al. 2008).

No data on pollution tolerant and sensitive diatoms species for assessment of the ecological status of freshwater ecosystems are available yet in Turkish. Direct adoption of foreign diatom index scores (Rott et al., 1999; Potapova and Charles, 2003; Dell'Uomo, 2004; Kelly et al., 2008) can lead to erroneous interpretation of water quality, because there are limited overlaps in species composition among different regions (Pan and Stevenson, 1996). Regional variation in each ecoregion, especially in geology, climate, land-use, and anthropogenic activities, can significantly change environmental factors, constraints, and regulation of diatom assemblages (Stevenson, 1997; Biggs et al., 1998; Soininen, 2007). Besides, the use of diatoms to assess ecological integrity of water bodies has a long history in different regions. This prompted the first attempt to determine trophic weight and indicator values of diatoms species in terms of tolerance based on total phosphorus (TP) variation in the aquatic ecosystems of Turkey. It has already been known that TP variation as a major environmental gradient could affect diatom species composition and their characteristic traits. The present study aimed to investigate the distribution of benthic diatom species related to TP concentration in eight basins of Turkey and determine the trophic weight and indicator values of species, which could serve to develop a new diatom metric called Trophic Index-Turkey (TIT).

2. Materials and methods

Water and diatom samples were collected at seasonal intervals at each of the stations from 8 basins of Turkey (Lower Euphrates, Ceyhan, the West Mediterranean, the North Aegean, Sakarya, the West Black Sea, the East Black Sea, and Aras) (Figure 1). A total of 225 stations, including rivers and creeks, were sampled from summer 2014 to summer 2015.

The epilithic samples were collected in riffle areas from stones by scraping the upper surface of stones with a toothbrush in 100 mL of distilled water according to the European standard methods (CEN, 2003, 2004). Algal samples were fixed with Lugol-glycerol solution. Collected water samples were stored in coolers with ice packs until transferred to the laboratory for chemical analyses. TP was the only chemical variable used in this study and its values were measured using a standard method (APHA, 2012)

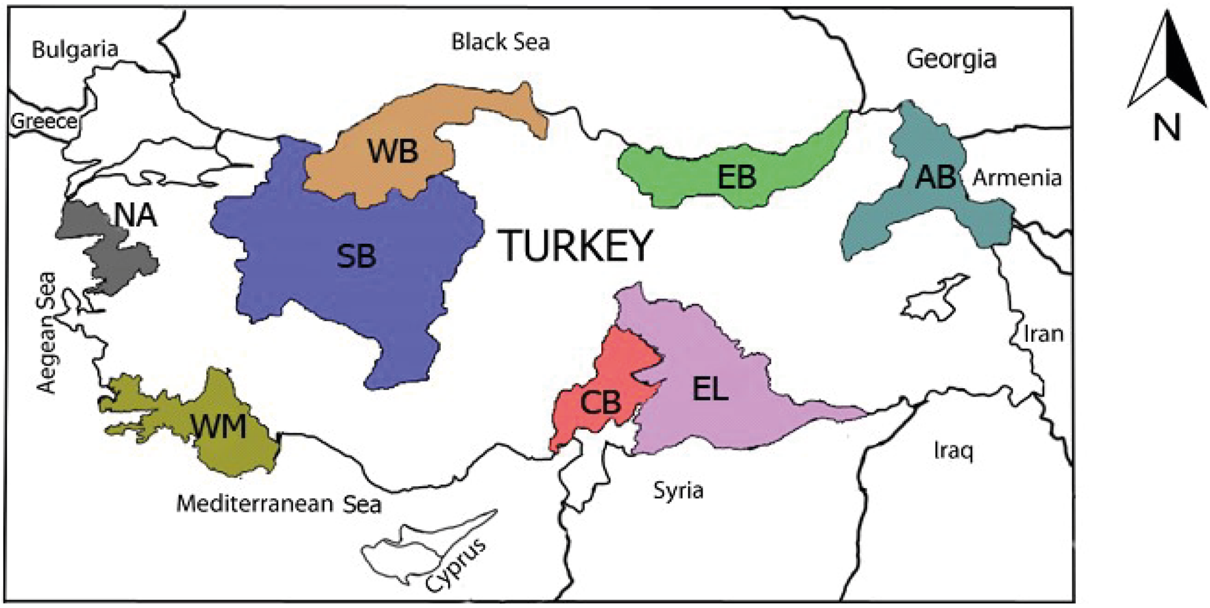

Figure 1. Map of the eight basins. Different colors indicate different basins. EL is the Lower Euphrates basin; CB is the Ceyhan basin; WM is the West Mediterranean basin; NA is the North Aegean basin; SB is the Sakarya basin; WB is the West Black Sea basin; EB is the East Black Sea basin; AB is the Aras basin.

The European standard methods (CEN, 2003, 2004, 2009) were applied for the identification and enumeration of diatom taxa. At least 400 valves of diatom species were counted under a light microscope (Olympus BX53) equipped with a DP73 model digital camera and imaging software (Olympus CellSens Vers. 1.6) at 1000× magnification to estimate the relative abundance of taxa. The primary key books (Krammer and Lange-Bertalot, 1991a, 1991b, 1999a, 1999b; Lange-Bertalot, 2001; Krammer, 2000, 2002) were used for diatom species identification.

The percentages of each diatom species throughout the 8 basins were determined based on TP classes. Median analysis of each diatom species related to TP variation was determined by using SPSS 16.0 (SPSS Inc., Chicago, IL, USA). Weighted averaging regression was used to estimate diatom species optima (u_k) and tolerance (t_k) levels for TP. The weighted average method assesses only a single pressure (e.g., nutrients) or related pressures of environmental factors on organisms.

According to the distribution of diatom species based on TP classes, trophic weight and indicator values were determined as described by Rott et al. (1999) and Binder (2001). Several species marked with an asterisk in the Table were observed only once during the study period; therefore, they were not used to calculate the trophic index. The trophic weight and indicator values were then used to develop a new diatom-based trophic index called the TIT based on the formula of Zelinka and Marvan (1961) and Rott et al. (1999).

$$TIT = \frac{\sum_{i=1}^{n} b_i * e_i * c_i}{\sum_{i=1}^{n} e_i * c_i}$$

b_i: *i*th taxon trophic weight based on TP classes (0.3–5),
e_i: *i*th taxon indicator value (0–5), and
c_i: the percentage of valves of the *i*th species in a sample.

3. Results

A total of 219 diatom species belonging to 34 genera were identified during the study in the water bodies (Table). *Bacillaria vulgaris*, *Clevamphora ovalis*, *Cocconeis placentula*, *Cymbella excisa*, *Cymbella tumida*, *Encyonema minutum*, *Encyonema silesiacum*, *Fragilaria capucina*, *Gomphonema parvulum*, *Melosira varians*, *Navicula cryptocephala, Navicula lanceolata*, *Navicula viridula*, *Nitzschia acicularis*, *Nitzschia palea*, and *Ulnaria ulna* were commonly found species. Some diatom species such as *Amphora inariensis*, *Aneumastus tuscula*, *Cocconeis scutellum*, *Cosmioneis pusilla*, *Craticula halophila*, *Cymbella gracilis*, *Cymbella mesiana*, *Denticula kuetzingii*, *Diploneis modica*, *Hantzschia distinctepunctata*, *Kobayasiella jaagii*, *Navicula seibigiana*, and *Nitzschia inconspicua* were observed only once during the studied period. The aforementioned rare species were only observed at the Lower Euphrates and West Mediterranean basins in the Mediterranean region.

The sampling stations of the eight basins revealed temporal and spatial differences between TP values during the study period. The TP content changed not only from one sampling station to another but also varied for the same station at different sampling seasons. Understanding the relationships of geographical and environmental factors with diatom distribution is an important process for development of diatom-based indicators for water quality assessment. The frequencies of TP values based on TP classes are given in Figure 2. Three TP classes (100–249, 250–500, and >500 µg L^{-1}) had higher TP frequency than the other ones. Diatom assemblages preferred various TP values with different frequencies in the eight basins. Optima, tolerance, median, trophic weight, and indicator values of diatom taxa for TP are given in the Table.

Diatom species such as *Craticula cuspidata*, *Encyonema ventricosum*, *Gomphonema augur*, *Navicula cuspidata*, *N. tripunctata*, *N. trivialis*, *Nitzschia amphibia*, *N. clausii*, *N. filiformis*, *N. linearis*, *N. palea*, *N. umbonata*, and *Tryblionella hungarica* showed high trophic weight values, while *Achnanthidium minutissimum*, *Adlafia bryophila*, *Amphora libyca*, *Cymbella excisa*, *Diatoma tenuis*, *Didymosphenia geminata*, *Encyonema silesiacum*, *Gomphocymbellopsis ancyli*, *Hannaea arcus*, *Meridion circulare*, *Navicula margalithii*, and *Navicula radiosa* were associated with low trophic weight values.

4. Discussion

The relationships between diatoms and environmental parameters can be quantified to make diatoms appropriate quantitative indicators of ecological conditions in ecosystems (Pan and Stevenson, 1996; Oliveira et al., 2001). Diatom communities respond quickly to environmental changes because of their short life cycles, rapid dispersal, and a large number of species with differing tolerances to physical and chemical variables (Lotter et al., 1999). Species diversity and abundance of diatoms are controlled by environmental factors like nutrients, temperature, light intensity, grazing pressure, substrate stability, and discharge (Izagirre and Elosegi, 2005). Phosphorus is thought to be the most important nutrient responsible for eutrophication in these rivers (Rott et al., 2003; Potapova et al., 2004). The diatom assemblages preferred various TP values with different frequencies in the eight basins (Figure 2) and the optimal TP values changed from one species to another in the water bodies during the study period (Table).

Table. Trophic weight and indicator values of diatom taxa associated with various freshwater ecosystems in 8 basins of Turkey based on total phosphorous (TP) classes compared to previous results. Asterisk indicates that species were observed only once during the studied period, which were not used to calculate the trophic index. Weighted averaging regression was used to estimate diatom species optima (u_k) and tolerance (t_k) levels for TP. n is the frequency of species. TW is trophic weight and g is indicator value.

					This study		Rott et al. (1999)		Binder (2001)	
Species	n	median	u_k	t_k	bi	ei	TW	G	tw	g
Achnanthes brevipes C.Agardh	3	0.296	1.030	1.003	3.5	3				
Achnanthidium exiguum (Grunow) Czarnecki	42	0.110	0.192	0.242	2.4	2				
Achnanthes impexa Lange-Bertalot	2	0.630	0.183	0.285	2.4	4				
Achnanthidium minutissimum (Kützing) Czarnecki	61	0.052	0.106	0.378	1.1	1	1.2	1	1.2	1
Adlafia bryophila (J.B.Petersen) Lange-Bertalot	16	0.047	0.174	0.306	1.2	2	1.3	2	0.6	4
Amphora libyca Ehrenberg	9	0.050	0.068	0.128	0.9	2	3.5	5	3.5	5
Amphora inariensis Krammer *	1	0.070	0.070	0.000	1.8	5	2.1	1	3.1	4
Aneumastus stroesei (Østrup) D.G.Mann	3	0.173	0.310	0.384	1.8	1	1.8	2		
Aneumastus tuscula (Ehrenberg) D.G.Mann & A.J.Stickle*	1	0.239	0.239	0.000	2.3	5	1.8	1		
Asterionella formosa Hassall	4	0.150	0.175	0.100	2.9	4	1.8	2	2.6	4
Aulacoseira granulata (Ehrenberg) Simonsen	61	0.101	0.483	0.779	2.5	0				
Aulacoseira italica (Ehrenberg) Simonsen	2	0.100	0.100	0.000	2.3	5	1.4	2	2.6	0
Brebissonia lanceolata (C.Agardh) R.K.Mahoney & Reimer	77	0.110	0.223	0.582	2.0	0	1.3	0		
Bacillaria vulgaris (Bory) Ehrenberg	253	0.100	0.256	0.323	2.3	0	2	0	2	0
Caloneis amphisbaena (Bory) Cleve	43	0.198	0.519	0.445	3.2	2	3.9	2	3.9	5
Caloneis amphisbaena var. *subsalina* (Donkin) Cleve	56	0.100	0.252	0.225	2.7	1				
Caloneis schumanniana (Grunow) Cleve	5	0.105	0.313	0.190	2.9	4	1.9	0	3.5	5
Caloneis silicula (Ehrenberg) Cleve	7	0.175	0.232	0.316	2.6	3	2.5	0		
Clevamphora ovalis (Kützing) Mereschkowsky	107	0.210	0.606	0.821	2.9	2	3.3	2	3.3	4
Cocconeis disculus (Schumann) Cleve*	1	0.060	0.060	0.000	1.7	5	2.2	3		
Cocconeis pediculus Ehrenberg	30	0.100	0.120	0.137	1.9	0	2.6	2	2.6	3
Cocconeis placentula Ehrenberg	465	0.128	0.369	0.598	2.6	0	2.6	2	2.4	0
Cocconeis placentula var. *placentula* Ehrenberg	5	0.090	0.100	0.030	3.1	1				
Cocconeis placentula var. *lineata* (Ehrenberg) V.Heurck*	1	0.980	0.980	0.000	4.0	5	2.3	2		
Cocconeis scutellum Ehrenberg*	1	0.060	0.060	0.000	1.7	5				
Cosmioneis pusilla (W.Smith) D.G.Mann & A.J.Stickle*	1	0.090	0.090	0.000	2.3	5				
Craticula accomoda (Hustedt) D.G.Mann	2	0.740	0.755	0.074	4.0	5	3.9	5	4	5
Craticula cuspidata (Kützing) D.G.Mann	11	0.400	0.898	1.525	3.6	3	2	0		
Craticula halophila (Grunow) D.G.Mann*	1	0.132	0.132	0.000	2.5	5	3.4	5		
Cyclotella atomus Hustedt	18	0.104	1.784	1.887	3.3	2				
Cyclotella bodanica Eulenstein	15	0.145	0.306	0.246	2.7	1				
Cyclotella iris Brun & Héribaud-Joseph	42	0.163	0.563	0.535	2.8	2				
Cyclotella meneghiniana Kützing	176	0.153	0.677	1.171	2.8	2	2.8	5	4	5
Cyclotella ocellata Pantocsek	36	0.081	0.164	0.253	1.7	1	1.5	1		
Cyclotella radiosa (Grunow) Lemmermann*	1	0.060	0.060	0.000	1.7	5	2.3	1	1.6	3
Cyclotella striata (Kützing) Grunow	15	0.254	0.242	0.203	2.7	0				
Cymatopleura elliptica (Brébisson) W.Smith	31	0.200	0.501	0.648	2.6	2	2.9	3		
Cymatopleura solea (Brébisson) W.Smith	61	0.194	0.392	0.511	3.0	1	3.1	3	3.6	5
Cymbella aspera (Ehrenberg) Cleve	2	0.223	0.181	0.052	3.0	4	1.7	1		
Cymbella cistula (Hemprich) Kirchner	46	0.051	0.164	0.232	1.8	0	2.3	1	1.1	5
Cymbella cymbiformis Agardh	13	0.345	0.383	0.280	3.2	1	1.8	3		
Cymbella ehrenbergii Kützing	10	0.160	0.194	0.144	2.4	2	2.2	3		
Cymbella excisa Kützing	275	0.080	0.163	0.390	1.3	1	0.7	4	0.7	4

Table. (Continued).

					This study		Rott et al. (1999)		Binder (2001)	
Species	n	median	u_k	t_k	bi	ei	TW	G	tw	g
Cymbella gracilis (Rabenhorst) Cleve*	1	0.300	0.300	0.000	3.2	5	0.6	4		
Cymbella hantzschiana Krammer	11	0.445	1.417	1.422	3.5	2				
Cymbella helvetica Kützing	30	0.151	0.308	0.278	2.7	1	1.4	2	1.4	0
Cymbella hustedtii Krasske	2	0.175	0.191	0.144	1.9	2	1.2	2		
Cymbella neoleptoceros Krammer	9	0.150	0.517	0.377	3.0	2	1.3	0		
Cymbella parva (W.Smith) Kirchner	2	0.350	0.119	0.222	0.6	4				
Cymbella proxima Reimer in Patrick & Reimer	4	0.282	0.269	0.138	3.1	3	1.2	2		
Cymbella tumida (Brébisson) van Heurck	110	0.114	0.277	0.297	2.5	1	0.6	2	0.1	5
Cymbella tumidula Grunow*	1	0.050	0.050	0.000	1.0	5	0.6	2		
Cymbella turgidula Grunow	4	0.045	0.042	0.035	0.3	4				
Cymbellafalsa diluviana (Krasske) Lange-Bertalot & Metzeltin	3	0.090	0.086	0.022	1.5	2				
Cymbopleura amphicephala (Nägeli) Krammer	6	0.078	0.169	0.222	1.3	1	1.1	3		
Cymbopleura naviculiformis (Auerswald ex Heiberg) Krammer	43	0.150	0.272	0.258	2.6	1	1.8	1	3.6	5
Denticula elegans Kützing	65	0.152	0.419	0.549	2.4	1	1.8	2		
Denticula kuetzingii Grunow*	1	0.030	0.030	0.000	0.3	5	1	2		
Denticula subtilis Grunow	5	0.198	0.495	0.251	3.6	3				
Denticula tenuis Kützing	3	0.041	0.075	0.116	1.1	3	1.4	3	1.4	3
Denticula valida (Pedicino) Grunow	2	0.435	0.600	0.167	3.8	4				
Diatoma ehrenbergii Kützing	9	0.040	0.085	0.196	0.8	3	1.6	2	1.6	1
Diatoma moniliformis (Kützing) D.M.Williams	21	0.272	0.256	0.322	2.2	0	2	3	1.2	0
Diatoma tenuis C.Agardh	12	0.053	0.060	0.057	1.1	1				
Didymosphenia geminata (Lyngbye) M. Schmidt	61	0.053	0.098	0.014	1.0	2	0.6	1		
Diploneis elliptica (Kützing) Cleve	5	0.100	0.179	0.131	2.6	2	1.7	2		
Diploneis littoralis (Donkin) Cleve	2	0.315	0.280	0.055	3.0	4				
Diploneis modica Hustedt*	1	0.730	0.730	0.00	4.0	5	1.4	0	1.4	0
Encyonema cespitosum Kützing	7	0.110	0.232	0.129	2.8	5	2.1	0	2.1	0
Encyonema leibleini (C.Agardh) W.J.Silva, R.Jahn, T.A.Veiga Ludwig & M.Menezes	76	0.094	0.134	0.160	1.6	0	2.3	1	1.6	3
Encyonema mesianum (Cholnoky) D.G.Mann*	1	0.354	0.354		5.0	5	1.8	0		
Encyonema minutum (Hilse) D.G.Mann	133	0.081	0.205	0.366	1.7	1	2	1	2	1
Encyonema silesiacum (Bleisch) D.G.Mann	123	0.092	0.155	0.373	1.1	2	2	0	2	0
Encyonema ventricosum (C.Agardh) Grunow	6	0.127	1.039	0.696	3.4	2				
Epithemia adnata (Kützing) Brébisson	22	0.100	0.367	0.237	2.8	2	2.2	2		
Epithemia argus (Ehrenberg) Kützing	8	0.092	0231	0.299	2.3	2	1.1	2		
Epithemia cistula (Ehrenberg) Ralfs*	1	0.354	0.354	0.000	3.4	5				
Epithemia frickei Krammer in Lange-Bertalot & Krammer	2	0.539	0.623	0.484	2.8	2				
Epithemia goeppertiana Hilse*	1	0.030	0.030	0,000	0,3	5				
Epithemia sorex Kützing	33	0.139	0.230	0.311	2.4	1	2.7	2		
Epithemia turgida (Ehrenberg) Kützing	2	0.044	0.048	0.010	1.3	2	2.3	2		
Eunotia bilunaris (Ehrenberg) Schaarschmidt*	1	0.660	0.660	0.000	4.0	5	0.7	0	0.6	5
Eunotia tenella (Grunow) Hustedt	6	0.070	0.112	0.049	2.3	3				
Fragilaria acus (Kützing) Lange-Bertalot	40	0.109	0.371	0.363	2.7	1				
Fragilaria biceps Ehrenberg	34	0.114	0.318	0.416	2.4	0	3.5	0		
Fragilaria capucina Desmazières*	101	0.100	0.283	0.325	2.4	0	1.8	2	0.9	4
Fragilaria crotonensis Kitton	11	0.250	0.263	0.121	2.9	3			3.3	5

Table. (Continued).

					This study		Rott et al. (1999)		Binder (2001)	
Species	n	median	u_k	t_k	bi	ei	TW	G	tw	g
Fragilaria dilatata (Brébisson) Lange-Bertalot	12	0.080	1.233	1.726	2.5	0	2.7	0		
Fragilaria parasitca var. *subconstricta Grunow**	1	0.150	0.150	0.000	2.9	5				
Fragilaria tenera (W.Smith) Lange-Bertalot	2	0.099	0.031	0.047	0.3	5	1	2	1.5	0
Fragilaria vaucheriae (Kützing) J.B.Petersen	3	0.664	1.518	0.503	3.9	4				
Geissleria schoenfeldii (Hustedt) Lange-Bertalot	2	0.071	0.065	0.018	1.9	4	1.9	1		
Gomphocymbellopsis ancyli (Cleve) Krammer	12	0.088	0.085	0.083	1.1	2	0.9	2		
Gomphonema acuminatum Ehrenberg	28	0.133	0.352	0.348	3.0	2	2.5	2		
Gomphonema angustatum (Kützing) Rabenhorst	37	0.140	0.416	0.686	2.5	1				
Gomphonema angustum C.Agardh	27	0.069	0.196	0.206	2.3	1	1	3	1	3
Gomphonema augur Ehrenberg	4	0.282	0.719	0.622	3.4	2	3.1	1		
Gomphonema bohemicum Reichelt & Fricke	3	0.675	0.563	0.507	3.3	2	0.6	1	3.8	5
Gomphonema gracile Ehrenberg	16	0.106	0.362	0.325	3.0	1			3.6	5
Gomphonema minutum (C.Agardh) C.Agardh	43	0.080	0.217	0.473	1.8	0	2.2	1	2.2	0
Gomphonema olivaceum (Hornemann) Brébisson	60	0.163	0.215	0.254	1.3	0	2.9	1	2	0
Gomphonema gracile Ehrenberg	16	0.106	0.362	0.325	3.0	1			3.6	5
Gomphonema parvulum (Kützing) Kützing	328	0.147	0.664	1.143	2.8	1	3.6	2	3.7	5
Gomphonema pseudoaugur Lange-Bertalot	2	0.085	0.074	0.010	1.8	4	3.7	3	4	5
Gomphonema subclavatum (Grunow) Grunow	2	0.111	0.072	0.052	1.5	4				
Gomphonema truncatum Ehrenberg	55	0.100	0.323	0.393	2.5	0	1.9	1		
Gyrosigma acuminatum (Kützing) Rabenhorst	59	0.240	0.277	0.196	2.8	2	2.5	2	3.7	5
Gyrosigma attenuatum (Kützing) Rabenhorst	18	0.100	0.485	1.429	2.0	2	2.6	3		
Gyrosigma scalproides (Rabenhorst) Cleve	50	0.182	0.547	0.649	3.1	2	2.3	1		
Grunowia tabellaria (Grunow) Rabenhorst	4	0.040	0.288	0.197	2.3	2				
Halamphora coffeiformis (C.Agardh) Levkov	4	0.143	0.461	0.261	3.4	2				
Halamphora subcapitata (Kisselew) Levkov	2	0.039	0.039	0.001	0.6	4				
Halamphora veneta (Kützing) Levkov	6	0.067	0.083	0.142	1.1	3	3.8	2	3.9	5
Hannaea arcus (Ehrenberg) R.M.Patrick	64	0.053	0.057	0.072	0.8	2	1	3	1	3
Hantzschia amphioxys (Ehrenberg) Grunow	23	0.128	0.303	0.403	1.8	0	3.6	3	3.7	5
Hantzschia distinctepunctata Hustedt*	1	0.070	0.070		1.7	5				
Hantzschia weyprechtii Grunow*	1	0.070	0.070		1.7	5				
Hippodonta capitata (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski	9	0.150	0.277	0.356	2.1	0	3.4	3	3.8	5
Karayevia clevei (Grunow) Round	2	0.035	0.031	0.003	0.3	4	2.1	0		
Kobayasiella jaagii (Meister) Lange-Bertalot	1	0.070	0.070	0.000	1.7	5				
Melosira lineata (Dillwyn) C.Agardh	18	0.070	0.193	0.189	1.4	0				
*Melosira undulata (*Ehrenberg) Kützing	9	0.128	0.192	0.179	2.7	3				
Melosira varians C.Agardh	176	0.110	0.381	0.108	2.6	0	2.9	4	2.9	4
Navicula capitatoradiata H.Germain	32	0.084	0.193	0.354	1.7	0	3.3	4	3.2	4
Navicula cari Ehrenberg	8	0.730	0.750	0.397	3.8	4	2.6	1		
Navicula cincta (Ehrenberg) Ralfs in Pritchard	14	0.163	0.398	0.267	3.0	2	3.3	2		
Navicula cryptocephala Kützing	242	0.158	0.430	0.213	2.8	2	3.5	4	3.5	4
Navicula cryptonella Lange-Bertalot	36	0.352	0.443	0.336	3.3	2	2.3	1	2.3	1
Navicula cuspidata (Kützing) Kützing	11	0.222	0.537	0.400	3.3	2	3.8	3	3.9	5
Navicula densilineolata (Lange-Bertalot) Lange-Bertalot*	1	1.070	1.070	0.000	4.0	5				
Navicula exigua Gregory	7	0.510	1.955	1.319	3.9	5	2.9	3	2.4	0
Navicula gottlandica Grunow*	1	0.070	0.070	0.000	1.7	5	1.5	2		

Table. (Continued).

					This study		Rott et al. (1999)		Binder (2001)	
Species	n	median	u_k	t_k	bi	ei	TW	G	tw	g
Navicula gregaria Donkin	3	0.140	0.165	0.123	2.2	2	3.5	4	3.4	4
Navicula lanceolata (C.Agardh) Kützing	86	0.069	0.143	0.172	1.9	0	3.5	4	3.5	5
Navicula laterostrata Hustedt*	1	0.100	0.100	0.000	2.3	5	1.4	2		
Navicula leptostriata Jørgensen*	1	0.390	0.390	0.000	3.4	5				
Navicula margalithii Lange-Bertalot	46	0.040	0.082	0.151	0.8	2				
Navicula menisculus Schumann	4	0.236	0.253	0.219	2.6	2	2.7	2	1.8	4
Navicula oppugnata Hustedt	75	0.175	0.472	0.712	2.8	0				
Navicula peregrina (Ehrenberg) Kützing	2	0.130	0.126	0.090	1.9	2				
Navicula phyllepta Kützing	10	0.189	0.443	0.336	3.3	3	2.9	3	3.2	4
Navicula radiosa Kützing	63	0.070	0.103	0.252	0.8	2				
Navicula recens (Lange-Bertalot) Lange-Bertalot	5	0.660	0.652	0.297	3.7	3	2.9	2		
Navicula rhynchocephala Kützing	6	0.085	0.278	0.263	2.3	2	2.3	1	3.8	5
Navicula rostellata Kützing	8	0.114	0.093	0.137	1.2	2				
Navicula seibigiana Lange-Bertalot*	1	3.345	3.385	1.294	4.0	5				
Navicula slesvicensis Grunow in van Heurck	3	0.063	0.048	0.040	1.1	2	3	2		
Navicula sp.	14	0.275	0.902	1.830	2.4	2				
Navicula sp.2	2	0.165	0.191	0.133	2.0	2				
Navicula tripunctata (O.F.Müller) Bory	40	0.178	0.333	0.348	2.9	2	3.1	3	2.7	2
Navicula trivialis Lange-Bertalot	20	0.540	0.820	0.933	3.4	2	3.3	1	3.2	0
Navicula veneta Kützing	3	0.068	0.100	0.086	2.0	4	3.5	5	3.5	5
Navicula viridula (Kützing) Ehrenberg	129	0.117	0.391	0.902	2.3	0	3.5	4	3.5	4
Navigeia modica (Hustedt) L.N.Bukhtiyarova*	1	0.030	0.030	0.000	0.3	5				
Neidium affine (Ehrenberg) Pftizer	2	0.123	0.123	0.005	2.9	5	0.6	2		
Neidium dubium (Ehrenberg) Cleve	3	0.044	0.045	0.027	0.8	0	2.3	2		
Nitzschia acicularis (Kützing) W.Smith	124	0.106	0.303	0.479	2.8	1	3.6	5	3.6	5
Nitzschia amphibia Grunow	4	0.510	0.991	0.289	3.8	5	3.8	5	3.8	5
Nitzschia brevissima Grunow in Van Heurck	4	0.695	0.511	0.312	3.5	4	2.9	2		
Nitzschia clausii Hantzsch	10	0.291	0.392	0.157	3.3	2	3.9	2	3.9	5
Nitzschia denticula Grunow	34	0.100	0.296	0.440	2.2	0				
Nitzschia dissipata (Kützing) Rabenhorst	25	0.100	0.257	0.954	2.1	0	2.4	2	2.4	1
Nitzschia dubia W.Smith	2	0.035	0.031	0.003	0.3	4	2.9	2		
Nitzschia filiformis (W.Smith) Van Heurck	6	0.960	1.976	1.725	3.8	4	3.7	2	3.7	5
Nitzschia flexa Schumann	40	0.100	0.217	0.226	2.4	0				
Nitzschia fonticola (Grunow) Grunow	5	0.070	0.056	0.027	1.3	3	1.9	0	1.9	0
Nitzschia frustulum (Kützing) Grunow	11	0.150	0.280	0.311	2.9	2	3.3	4	3.2	4
Nitzschia hantzschiana Rabenhorst	3	0.139	0.244	0.359	2.0	2	2	3	2.2	4
Nitzschia inconspicua Grunow*	1	0.587	0.587	0.000	4.0	5	3.1	1	3.1	0
Nitzschia lanceolata W.Smith	5	0.240	0.707	0.468	3.1	2				
Nitzschia linearis (C.Agardh) W.Smith	3	0.195	0.407	0.239	3.1	2	3.4	4	3.4	4
Nitzschia incurvata var. *lorenziana* R.Ross	2	0.595	0.240	0.000	2.9	5				
Nitzschia microcephala Grunow	3	0.037	0.034	0.003	0.3	3	3.9	3	3.9	5
Nitzschia obtusa W.Smith	2	0.214	0.225	0.015	2.9	5				
Nitzschia palea (Kützing) W.Smith	122	0.167	0.875	1.212	3.3	2	3.3	3	3.3	4
Nitzschia recta Hantzsch ex Rabenhorst	42	0.145	0.500	0.029	2.5	0	3	3	3	4
Nitzschia sigmoidea (Nitzsch) W.Smith	46	0.100	0.364	0.094	2.7	1	3.8	4	3.8	5
Nitzchia sp.	23	0.163	0.451	0.364	3.0	1				

Table. (Continued).

					This study		Rott et al. (1999)		Binder (2001)	
Species	n	median	u_k	t_k	bi	ei	TW	G	tw	g
Nitzschia umbonata (Ehrenberg) Lange-Bertalot	14	0.820	1.616	1.504	3.7	4	3.8	3	3.9	5
Nitzschia vermicularis (Kützing) Hantzsch	15	0.310	0.274	0.256	2.3	0	2.2	0		
Odontidium hyemale (Roth) Kützing	23	0.121	0.131	0.205	1.2	2	1	4	0.9	4
Odontidium mesodon (Kützing) Kützing	42	0.050	0.071	0.116	0.9	2	0.7	4	0.7	4
Paraplaconeis placentula (Ehrenberg) M.S.Kulikovskiy & Lange-Bertalot	8	0.150	0.248	0.218	2.5	2	2.7	3		
Pinnularia biceps W.Gregory	2	0.245	0.251	0.085	3.2	3				
Pinnularia brebissonii (Kützing) Rabenhorst	8	0.345	0.398	0.145	3.3	3				
Pinnularia divergens W.Smith*	1	0.121	0.121	0.000	2.8	5	0.6	2		
Pinnularia sp.	3	0.090	0.090	0.000	2.3	5				
Pinnularia subcapitata W.Gregory	2	0.241	0.281	0.127	3.2	4	0.9	2	1.1	4
Pinnularia viridis (Nitzsch) Ehrenberg	12	0.305	0.312	0.309	2.7	1	1.3	2		
Placoneis clementis (Grunow) E.J.Cox	6	0.402	0.431	0.276	3.1	2	2.5	2		
Placoneis constans (Hustedt) E.J.Cox	2	0.660	0.673	0.200	3.7	3	2.9	1		
Placoneis elginensis (W.Gregory) E.J.Cox	1	0.030	0.030	0.000	0.3	5	2.1	2	1.9	5
Planothidium lanceolatum (Brébisson ex Kützing) Round & Bukhtiyarova	46	0.070	0.107	0.137	1.6	0	3.3	3	3.2	4
Platessa salinarum (Grunow) Lange-Bertalot*	1	0.076	0.076	0.000	2.3	5	2.3	2		
Prestauroneis protracta (Grunow) I.W.Bishop, Minerovic, Q.Liu & Kociolek	2	0.070	0.061	0.029	1.0	3	2.9	2		
Reimeria sinuata W.Gregory	3	0.121	0.318	0.277	3.1	0	1.8	0		
Rhoicosphenia abbreviata (C.Agardh) Lange-Bertalot	9	0.185	0.419	0.292	3.0	2	2.9	2	2.9	2
Rhoicosphenia curvata Kützing	74	0.118	0.284	0.129	2.7	1				
Rhopalodia gibba (Ehrenberg) O.Müller	19	0.100	0.322	0.465	2.3	0	2.7	2		
Sellaphora pupula (Kützing) Mereschkovsky	12	0.100	0.134	0.110	2.5	4			3.7	5
Staurosira construens Ehrenberg	5	0.030	0.387	0.194	2.3	2	2.3	2	3.4	4
Staurosirella pinnata (Ehrenberg) D.M.Williams & Round	2	0.285	0.405	0.061	3.4	5	2.2	14	2.1	0
Surirella angusta Kützing	12	0.126	0.483	0.378	2.9	2	3.7	3	3.7	5
Surirella biseriata Brébisson	21	0.100	0.756	1.659	2.6	2	2.1	2		
Surirella brebissonii Krammer & Lange-Bertalot	35	0.160	0.393	0.381	2.8	1	3.6	5	3.6	5
Surirella elegans Ehrenberg	8	0.120	0.135	0.068	2.4	3	2.7	3		
Surirella minuta Brébisson ex Kützing	16	0.111	0.550	0.990	2.5	0	3.8	3	3.8	5
Surirella ovalis Brébisson	17	0.160	0.357	1.009	2.7	2	2.2	0	2.2	0
Surirella ovata Kützing	15	0.069	0.119	0.129	1.4	2				
Surirella robusta Ehrenberg	28	0.160	0.295	0.400	2.9	1	1.4	0		
Surirella subsalsa W.Smith	6	0.069	0.100	0.108	1.8	4				
Tabularia fasciculata (C.Agardh) D.M.Williams &Round	25	0.180	0.173	0.178	2.0	0	3.5	3		
Tryblionella angustata W.Smith	48	0.425	1.738	2.018	3.5	3	2.6	2	3.5	5
Tryblionella calida (Grunow) D.G.Mann	3	0.190	0.877	1.039	3.2	2	3	2		
Tryblionella hungarica (Grunow) Frenguelli	38	0.154	0.317	0.455	3.3	2	3.9	3	4	5
Ulnaria biceps (Kützing) Compère	34	0.114	0.318	0.416	2.4	0	3.5	0		
Ulnaria capitata (Ehrenberg) Compère*	1	0.070	0.070	0.000	1.7	5				
Ulnaria ulna (Nitzsch) Compère	416	1.345	0.459	0.901	2.8	1	3.5	4	3.5	5

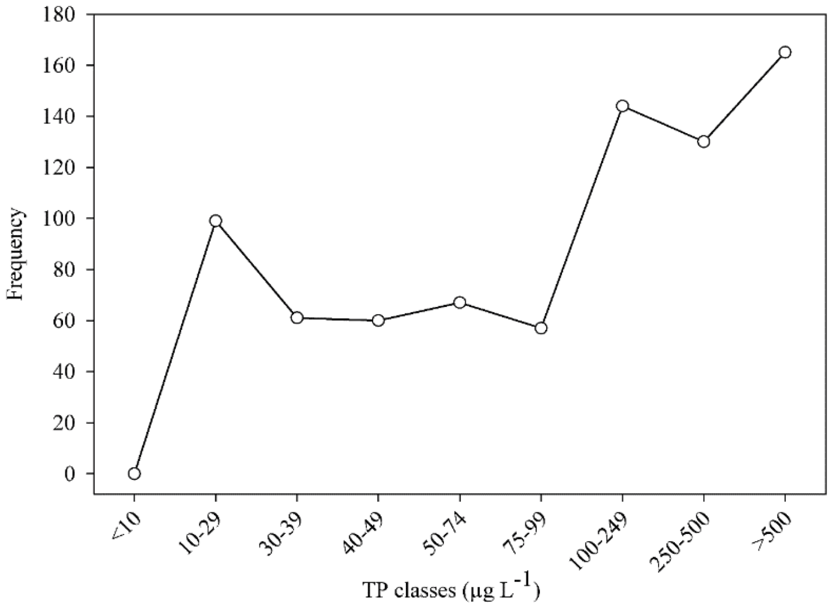

Figure 2. Frequency of TP values based on TP classes in eight basins.

A total of 219 diatom species were found in the running water systems (Table). This number is higher than those of a review study including the most common diatom taxa (129) from rivers, lakes, and reservoirs in Turkey (Solak et al., 2012b) and a limnological study about Felent Creek with 117 diatom taxa (Solak et al., 2012a). Most of the diatom taxa identified in the present study had not been reported in the previous studies (Solak et al., 2012a, 2012b). Most of the diatom species found in this study belong to the genera *Navicula* and *Cymbella* and were also commonly found in the world (Round, 1991; Rott et al., 1999; Krammer, 2002; Kelly et al., 2008). The occurrence of the diatom species changed not only from one sampling station to another but also varied at the same stations at different sampling seasons during the study period. The commonly found species in the present study (e.g., *Cocconeis placentula*, *Cymbella excisa*, *Bacillaria vulgaris*, *Ulnaria ulna*, *Gomphonema parvulum*, and *Navicula cryptocephala*) were widespread in various habitats in different regions (Rott et al., 1999; Potapova and Charles, 2003; Dell'Uomo, 2004; Kelly et al., 2008; Beltrami et al., 2012; Della Bella et al., 2012; Çelekli and Öztürk, 2014; Delgado and Pardo, 2014; Kelly et al., 2014).

Several diatom species (e.g., *E. ventricosum*, *Craticula cuspidata*, *Denticula subtilis*, *Gomphonema augur*, *Navicula cuspidata*, *Nitzschia amphibia*, *N. tripunctata*, *N. trivialis*, *N. clausii*, *N. palea*, and *N. umbonata*) with relatively high trophic values were not only commonly identified in this study, but are also widespread around the earth (Rott et al., 1999; Binder, 2001; Krammer, 2002; Potapova and Charles, 2003; Kelly et al., 2008; Beltrami et al., 2012; Della Bella et al., 2012; Delgado and Pardo, 2014; Kelly et al., 2014). However, many diatom taxa in this study showed different trophic weight levels compared to the results from Austria, Italy, and the United Kingdom (Rott et al., 1999; Binder, 2001; Dell'Uomo, 2004; Kelly et al., 2008).

The diatom species that mainly preferred low trophic values (e.g., *A. minutissimum*, *A. bryophila*, *D. geminata*, *G. ancyli*, *H. arcus*, and *M. circulare*) showed similar traits in the findings from Austria and the United Kingdom (Rott et al., 1999; Binder, 2001; Kelly et al., 2008).

As can be clearly seen in the Table, many diatom taxa (*Achnanthes brevipes*, *A. impexa*, *Achnanthidium exiguum*, *Halamphora coffeiformis*, *Halamphora subcapitata*, *Cymbella hantzschiana*, *C. turgidula*, *Denticula subtilis*, *Encyonema ventricosum*, *Ulnaria capitata*, *Fragilaria crotonensis*, *Gomphonema gracile*, *Melosira undulata*, *N. margalithii*, *N. oppugnata*, *N. rostellata*, *Nitzschia denticula*, *N. flexa*, *N. lanceolata*, *Pinnularia brebissonii*, and others) had their trophic weight values presented for the first time in the present study, compared to the diatom lists of Austria (Rott et al., 1999; Binder, 2001). This could be due to the regional variation of environmental factors, which could regulate diatom species composition and their TP optima (Biggs et al., 1998; Soininen, 2007). Besides, diatoms have a long history in aquatic ecosystems, which could change among different regions. Therefore, determination of diatom optima for different regions can improve the performance of diatom indicators. These results could notably affect trophic diatom indices to calculate the ecological quality ratio of water bodies for bioassessment. Furthermore, the taxonomic composition of different ecosystems is a major parameter for the assessment of ecological status (Karr and Chu, 1999; EC, 2009; Pongpan and Yuwadee, 2014).

The approach adopted in the present study is novel in that it uses trophic and indicators values determined in Turkey to develop a diatom metric called the TIT to evaluate the ecological status of running water bodies. A total of 219 diatom taxa were used to develop the TIT, which corresponds to 35.82% of the 631 diatoms taxa in Turkish freshwater bodies including rivers, lakes, and reservoirs as reported by Solak et al. (2012b). Considering the large number of studies related to diatom communities in lakes and reservoirs (Solak et al., 2012b), this percentage is representative to develop a diatom-based metric to assess running water in Turkey. These findings provided informative assessments of the biotic integrity of various water bodies and can be used to calculate the trophic index value for the bioassessment of freshwater ecosystems. These values can also be used for other running water ecological status bioassessments in Turkey and Mediterranean countries that have the same ecoregional characteristics.

The procedure used for defining the actual trophic and indicator values was based on the method described by Rott et al. (1999) and Binder (2001). These trophic values can be considered as a useful tool for evaluating the response of diatoms to changes in running water quality. The results of the first study indicated that each diatom assemblage was associated with various water bodies with different TP values and had different trophic weights due to their tolerant and sensitive responses to related environmental changes. These findings provided informative assessments of the biotic integrity of various water bodies and can be used to calculate the trophic index value for the bioassessment of freshwater ecosystems. Trophic parameters of the diatom list in the present study will be updated by taking data from different basins of Turkey. These values can also be used for other running water ecological status bioassessments in Turkey and Mediterranean countries that have the same ecoregional characteristics.

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