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# Evaluation of Ecological Quality Status with the Trophic Index (TRIX) Values in the Coastal Waters of the Gulfs of Erdek and Bandırma in the Marmara Sea

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## 1. Introduction

In developing countries, more than 90 percent of wastewater and 70 percent of industrial wastes are discharged into coastal waters without being treated (Creel, 2003). The entry of wastes into marine environment not only changes water quality parameters but also affects benthic organisms, causes habitat change and increases the risk of eutrophication and, thereby, causes the area to become susceptible. The Urban Wastewater Treatment Directive (UWTD; EC, 1991) defines eutrophication as the “enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned”. Karydis (2009) characterized “oligotrophic” waters as nutrient poor with low productivity, “eutrophic” waters as nutrient rich with high algal biomass and “mesotrophic” waters as moderate conditions. Hypoxia or even anoxia is the last stage of eutrophication (Gray, 1992) and this phase is often characterized as “dystrophic” (Karydis, 2009). In addition, eutrophication of coastal waters has been considered as one of the major threats to the health of marine ecosystems in the last few decades (Andersen et al., 2004; Yang et al., 2008). The risk of eutrophication may increase or decrease depending on the speed and direction of flow and wind. It can occur as a result of natural processes, for example, where there is upwelling of nutrient rich deep water to nutrient poor but light rich surface water of the photic zone of the water column (Jørgensen & Richardson, 1996). Cultural eutrophication arising from anthropogenic activities is particularly evident in marine areas with limited water exchange, and in lagoons, bays and harbours (Crouzet et al., 1999).

Various factors may increase the supply of organic matter to coastal systems, but the most common is clearly nutrient enrichment. The major causes of nutrient enrichment in coastal areas are associated directly or indirectly with meeting the requirements and demands of human nutrition and diet. The deposition of reactive nitrogen emitted to the atmosphere as

a consequence of fossil fuel combustion is also an important anthropogenic factor (Nixon, 1995). Nutrients are the essential chemical components of life in marine environment. Phosphorus and nitrogen are incorporated into living tissues, and silicate is necessary for the formation of the skeletons of diatoms and radiolaria (Baştürk et al., 1986). In the sea, most of the nutrients are present in sufficient concentration, and lack of some of them limits the growth of phytoplankton (Pojed & Kveder, 1977). While some nutrient enrichment may be beneficial, excessive enrichment may result in large algal blooms and seaweed growths, oxygen depletion and the production of hydrogen sulphide, which is toxic to marine life and can cause high mortality, red tide events, decreasing fishery yields, and nonreversible changes in ecosystem health (Daoji & Daler, 2004).

Trophic conditions of European coastal waters vary considerably from region to region and within regions. A trophic index (TRIX) characterizing eutrophic levels, was introduced by Vollenweider et al. (1998). The European Environmental Agency has evaluated this index and suggested that TRIX scales at regional level should be developed. TRIX values are very sensitive and any slight change of oxygen, chlorophyll *a*, dissolved inorganic nitrogen and total phosphorus concentrations results in changed index values (Boikova et al., 2008). This simple index seems to help synthesize key eutrophication variables into a simple numeric expression to make information comparable over a wide range of trophic situations (Anonymous, 2001).

Bays and gulfs are very important for fishing since they provide habitats for sheltering and reproduction for most living species. They are influenced by environmental conditions, especially pollution, very rapidly, which causes negative changes in their structures. Bays and gulfs are quieter compared to open seas and have a semi-closed structure, which increases the frequency of such events as eutrophication and red-tide events. The influence level of pollution on living organisms is directly related with the changes in species diversity, and the effects of pollution on a specific environment can be determined by monitoring the natural process. However, in order to achieve this, the most important requisite is to determine the ecological status of the area(s) that will be studied before pollution (Koray & Kesici, 1994). Seasonal changes and global warming considerably affects the biological structure of seas (Goffart et al., 2002). These effects in the marine environment come into being with different phenomena. For instance, mucilage formation in seas is the aggregation of organic substances that are produced by various marine organisms under special seasonal and trophic conditions (Innamorati et al., 2001; Mecozzi et al., 2001). In Turkish territorial waters, mucilage formation was observed firstly in the Gulf of İzmit in the Marmara Sea in October 2007 and mainly fisheries and tourism have been damaged seriously (Tüfekçi et al., 2010). Then, mucilage formations were reported on the shores of Büyükkada Island (Balkis et al., 2011) and in the Gulf of Erdek (Tüfekçi et al., 2010). This study is important because there is not a sufficient amount of comprehensive research conducted on the subject in the Gulfs of Erdek and Bandırma. Besides, the two gulfs are important for fishing and they are under the threat of heavy pollution.

In recent years, the scientific and technological advances have shown that studying sea and oceans, which cover 70% of the earth, is considerably important. Today in order to meet the increasing need for food, the studies on food sources in our seas have gained speed. This study aims to determine the ecological quality of coastal waters in the Gulfs of Erdek and Bandırma, and firstly the two gulfs will be compared in terms of environmental factors.

## 2. Material and methods

### 2.1 Study areas

The Marmara Sea forms “the Turkish Straits System” together with the Bosphorus and the Dardanelles. It has a surface area of 11,500 km<sup>2</sup> and the maximum depth is 1390 m. It is a small basin located between Asia and Europe. It is connected on the northeast with the Black Sea through the Bosphorus and on the southwest with the Aegean Sea through the Dardanelles (Ünlüata et al., 1990; Yüce & Türker, 1991; Beşiktepe et al., 1994). The brackish Black Sea waters with a salinity of about 17.6 ppt flow through the Bosphorus towards the Marmara Sea at the surface while the waters of Mediterranean origin with a salinity of about 38 ppt flow through the Dardanelles towards the Marmara Sea in a lower layer. There is an intermediate salinity mass with 25 m depth between these two water masses due to the difference in their densities (Ullyott & Pektaş, 1952; Yüce & Türker, 1991). The bottom water with a high salinity value includes a low amount of dissolved oxygen, and the water exchange and oceanographic conditions in the Marmara Sea are controlled by the two straits. The density stratification in the halocline impedes oxygen transfer from the surface layer that is rich in oxygen to the lower layer. Besides, biogenic particles in the bottom water increase oxygen consumption, which decreases the dissolved oxygen content of the lower water layer (Yüce & Türker, 1991; Beşiktepe et al., 2000).

The annual volume influx from the Black Sea to the Marmara Sea is nearly twice the salty water outflux from the Marmara basin to the Black Sea via the Bosphorus undercurrent (Ünlüata et al., 1990; Beşiktepe et al., 1994). Cyclonic alongshore currents in the Black Sea carry the polluted surface waters of the northwestern shelf as far as the Bosphorus region, with modified hydrochemical properties (Polat & Tuğrul, 1995). In addition, the salinity and nutrient contents of inflow slightly increase at the southern exit of the Bosphorus due to vertical mixing of the counter flows during the year. Concomitant photosynthetic processes in the Marmara upper layer, however, lead to consumption of biologically available nutrients and thus to a net export of particulate nutrients to the lower layer (Tuğrul et al., 2002). Primary production in the Sea is limited with halocline layer including the interface between 15 and 25 m (Polat & Tuğrul, 1995).

The oceanographic characteristics of the Gulfs of Erdek and Bandırma are similar to the Marmara Sea and the water column has a two-layer structure. The Gulf of Erdek has lower population density and industrial activities compared to the Gulf of Bandırma. The Biga River and the Gönen River flow into the Gulf of Erdek. The load of both rivers are affected by the mineral deposits and agricultural and food industries in their basin and the domestic wastes from the Boroughs of Biga and Gönen.

The Gulf of Bandırma is affected by industrial pollution and is more densely inhabited. The studies showed that the surface waters of the Gulf of Bandırma and the region that is on the northeast of the Kapıdağ Peninsula include more phosphate compared to the other parts of the Marmara Sea. This increase is caused by the domestic wastes and especially the fertilizer plant located in the Gulf. The Borough of Bandırma is rich in regards to nutrients both surface and ground waters. Most of the surface waters in Bandırma flow into the Susurluk River through Lake Manyas and the Kara River and reach the Marmara Sea. The most important harbor on the south of the Marmara Sea is located in this gulf. Although the intensive production of white meat and fertilizer raises the importance of the borough, it at the same time affects the Gulf of Bandırma negatively (Özelli & Özbaysal, 2001; Koç, 2002).

## 2.2 Sampling and primary analysis

Samples were collected from different depths of the water column (0.5, 15, 30 m) at three stations in each gulf, in total at six stations, seasonally (November, February, May, and August) for two years between November 2006 and August 2008 (Fig.1). The maximum depth at the stations is approximately 50 m. Photic zone, where photosynthesis occurs, was used as base in the selection of sampling depth. Water transparency was usually measured with the Secchi disk. A 3 l Ruttner water sampler with a thermometer was used for water analyses at each sampling point. The salinity was determined by the Mohr-Knudsen method (Ivanoff, 1972) and the dissolved oxygen (DO) by the Winkler method (Winkler, 1888).

Water samples for the determination of nutrients were collected in 100-mL polyethylene bottles and stored at -20 °C until the analysis in the laboratory. Nitrate+nitrite-N concentrations were measured by the cadmium reduction method using a “Skalar” autoanalyzer (APHA, 1999). Phosphate-P, Silicate-Si and chlorophyll *a* were analyzed by the methods described by Parsons et al. (1984). Chlorophyll *a* was measured after filtering 1 liter of the sample through Whatman GF/F filters. One milliliter of a 1% suspension of  $\text{MgCO}_3$  was added to the sample prior to filtration. Samples were stored in a freezer, and pigments were extracted in a 90% acetone solution and measured with a spectrophotometer.

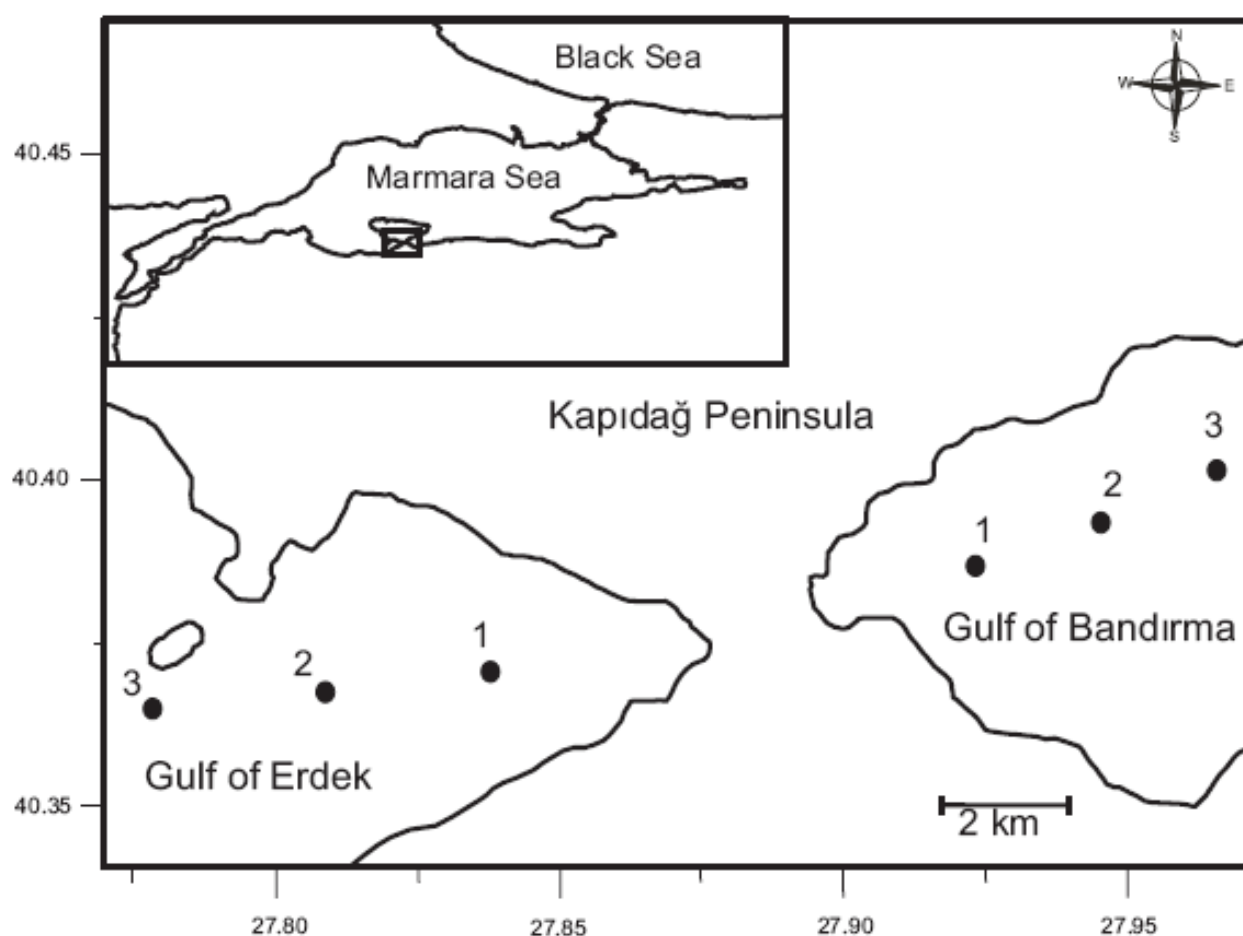


Fig. 1. Research stations in the Gulfs of Bandırma and Erdek



## 2.3 Data analysis

Trophic Index (TRIX) values were calculated in order to determine the eutrophication level of the sampling area and the quality of waters (Vollenweider et al., 1998). The index is given by:

$$\text{TRIX} = [\log_{10}(\text{Chl } a \cdot \text{D\%O} \cdot \text{N} \cdot \text{P}) + 1.5] / 1.2$$

Chl *a*= Chlorophyll *a* ( $\mu\text{g L}^{-1}$ ), D%O= Oxygen as an absolute deviation (%) from saturation, N= Dissolved inorganic nitrogen  $\text{N-NO}_3 + \text{NO}_2$  ( $\mu\text{g-at L}^{-1}$ ), P= Total phosphorus  $\text{P-PO}_4$  ( $\mu\text{g-at L}^{-1}$ ). Ammonium values were not used in nutrient ratios and calculation of TRIX, because  $\text{NH}_4\text{-N}$  values were not measured in this paper. TRIX was scaled from 0 to 10, covering a range of four trophic states (0-4 high quality and low trophic level; 4-5 good quality and moderate trophic level; 5-6 moderate quality and high trophic level and 6-10 degraded and very high trophic level) (Giovanardi & Vollenweider., 2004; Penna et al., 2004).

Spearman's rank correlation coefficient (Siegel, 1956) was used to detect any correlation among biotic (chlorophyll *a*) and abiotic variables (temperature, salinity, DO and nutrients), and Bray-Curtis similarity index in Primer v6 software, based on  $\log(x+1)$  transformation was calculated to detect the similarity between sampling stations (Clark & Warwick, 2001).

## 3. Results

The vertical distribution of temperature, salinity and dissolved oxygen in the coastal waters of the Gulfs of Bandırma and Erdek is shown in Figs. 2, 3. During the study, temperature, salinity and dissolved oxygen levels of the seawater ranged between 6.5 and 26 °C, 21.4 and 38.6 ppt, and 3.5 and 15.62  $\text{mg L}^{-1}$  in the gulfs, respectively. Also, chlorophyll *a* values ranged between 0.1 and 14.79  $\mu\text{g L}^{-1}$  (Figs. 2, 3).

In the Gulf of Bandırma, the highest temperature value (26 °C) was measured at the depth of 0.5 m at all stations (Fig. 2). Homogenous distribution of water temperature was observed at Station 1 in February 2007. Also, sudden changes were more pronounced after the depth of 15 m at all stations. In this Gulf, the highest salinity value (38.5 ppt) was determined at the depth of 30 m at Station 3 in November 2006. While upper layer salinity values were low, sudden increases were observed after the depth of 15 m. Dissolved oxygen content of the gulf was lower in the deeper layer compared to the upper. The highest DO value (15.62  $\text{mg L}^{-1}$ ) was measured at the depth of 15 m at Station 2 in November 2006, and the lowest (3.5  $\text{mg L}^{-1}$ ) at the depth of 30 m at Station 1 in May 2008. For chlorophyll *a* concentration, the highest value (14.79  $\mu\text{g L}^{-1}$ ) was determined at the depth of 0.5 m at Station 2 in August 2008 and higher chlorophyll *a* value was observed in the upper water column. The lowest value was detected at the depth of 30 m (0.21  $\mu\text{g L}^{-1}$ ) at Station 2 in May 2008. Water transparency was 4.5 m (February 2008) - 16 m (November 2006) in the Gulf of Bandırma.

In the Gulf of Erdek, the highest temperature value (25.5 °C) was recorded in the surface water at all stations in August 2007. Sudden temperature changes were detected after the depth of 15 m at all stations as in the Gulf of Bandırma. Salinity values ranged from 22.4 ppt (st.2, 0.5 m, May 2007) to 38.6 ppt (st.3, 30 m, November 2006). While a sudden increase was detected in salinity values after the depth of 15 m at Station 2 and Station 3, the values increased in some seasons and decrease in others at Station 1, which is a coastal station. As in the Gulf of Bandırma, oxygen values were determined to be higher in the upper layer and

showed decrease towards the deeper layers. The lowest value (3.78 mg L<sup>-1</sup>) was detected at the depth of 30 m at Station 3 in August 2008. During most of the sampling period, chlorophyll *a* values were higher in the euphotic zone and showed decrease in correlation with the increase of depth. Chlorophyll *a* values were between 0.10 µg L<sup>-1</sup>(st.3, 30 m, May 2008) and 2.83 µg L<sup>-1</sup> (st.3, 15 m, February 2008). Water transparency was 6 m (February 2008) - 15 m (February 2007) in this gulf.

Nutrient concentrations and TRIX index values are shown in Figs. 4, 5. The amounts of nitrate+nitrite-N (0.07-5.83 µg-at N L<sup>-1</sup>), phosphate-P (0.09-8.6 µg-at P L<sup>-1</sup>) and silicate-Si (0.05-21.62 µg-at Si L<sup>-1</sup>) concentrations were measured. The consumption of nitrogen and silica in the upper layer was determined to be higher in both of the gulfs. However, phosphorus values were quite high in the upper layer compared to the lower especially in August 2008. A similar situation was observed at Station 1 in February 2008. There were low levels of dissolved oxygen in the deeper layers, which were rich in nutrients.

Mean ratios of nutrients and chlorophyll *a* at the sampling stations are presented in Table 1. The lowest and highest mean ratios of N/P were 0.04 (0.5 m depth, in May 2007) and 4.73 (30 m depth, in May 2007) in the Gulf of Bandırma and 0.35 (0.5 m depth, in August 2007) and 7.08 (30 m depth, in May 2008) in the Gulf of Erdek, respectively. Also these ratios were recorded lower than the Redfield ratio (16/1). This result indicates that N is limiting nutrient for both gulfs. A considerable increase was observed in both N/P and Si/P ratios especially from the upper layer to the lower in both gulfs. Besides, these values were higher in the Gulf of Erdek compared to the Gulf of Bandırma. In both gulfs, N/Si ratio was lower than 1 during all sampling periods. P/Chl *a* ratio was low in the upper layer due to the increase of chlorophyll *a* value depending on phytoplankton activity and the use of phosphorus by these organisms.

Period	N/P			N/Si			Si/P			P/Chl <i>a</i>		
	0.5m	15m	30m	0.5m	15m	30m	0.5m	15m	30m	0.5m	15m	30m
<b>Gulf of Bandırma</b>												
Nov.2006	0.34	0.35	3.42	0.21	0.26	0.29	1.64	1.49	11.22	1.12	0.87	2.88
Feb.2007	0.35	0.13	3.82	0.19	0.07	0.52	1.80	1.81	7.76	0.66	0.70	3.28
May.2007	0.04	0.33	4.73	0.17	0.26	0.34	0.28	1.30	13.30	1.18	1.38	2.99
Aug.2007	0.65	0.23	3.18	0.45	0.21	0.27	4.20	1.81	11.39	0.98	0.80	1.89
Nov.2007	0.68	1.26	2.40	0.30	0.29	0.55	1.98	3.71	4.52	0.37	0.55	1.78
Feb.2008	0.57	0.47	3.08	0.19	0.24	0.70	3.29	1.90	4.39	0.57	0.19	0.49
May.2008	0.48	3.28	4.37	0.77	0.80	0.75	0.60	3.66	5.77	3.00	1.68	3.84
Aug.2008	0.08	0.08	2.37	6.25	2.38	1.35	0.02	0.17	3.19	0.64	0.58	0.72
<b>Gulf of Erdek</b>												
Nov.2006	0.68	2.32	4.70	0.12	0.30	0.36	6.05	7.33	12.88	0.25	1.18	1.91
Feb.2007	0.91	1.00	3.24	0.17	0.10	0.14	5.54	16.05	23.62	0.31	0.68	4.39
May.2007	0.85	0.55	3.70	0.13	0.07	0.21	6.45	13.11	17.78	0.19	0.25	2.06
Aug.2007	0.35	0.77	1.82	0.06	0.14	0.10	5.69	5.30	13.67	0.61	0.52	0.37
Nov.2007	0.72	1.47	0.97	0.44	0.66	0.49	1.42	1.98	2.62	0.61	1.02	6.42
Feb.2008	1.91	1.70	3.22	0.15	0.13	0.43	12.88	13.51	8.97	0.06	0.05	0.13
May.2008	1.80	2.33	7.08	0.92	0.54	0.75	1.93	4.60	9.42	0.35	0.52	4.93
Aug.2008	1.12	0.71	5.09	0.55	0.44	0.54	2.07	1.44	9.30	0.19	0.55	0.75

Table 1. The atomic ratios of nutrients and chlorophyll *a* at the sampling stations.

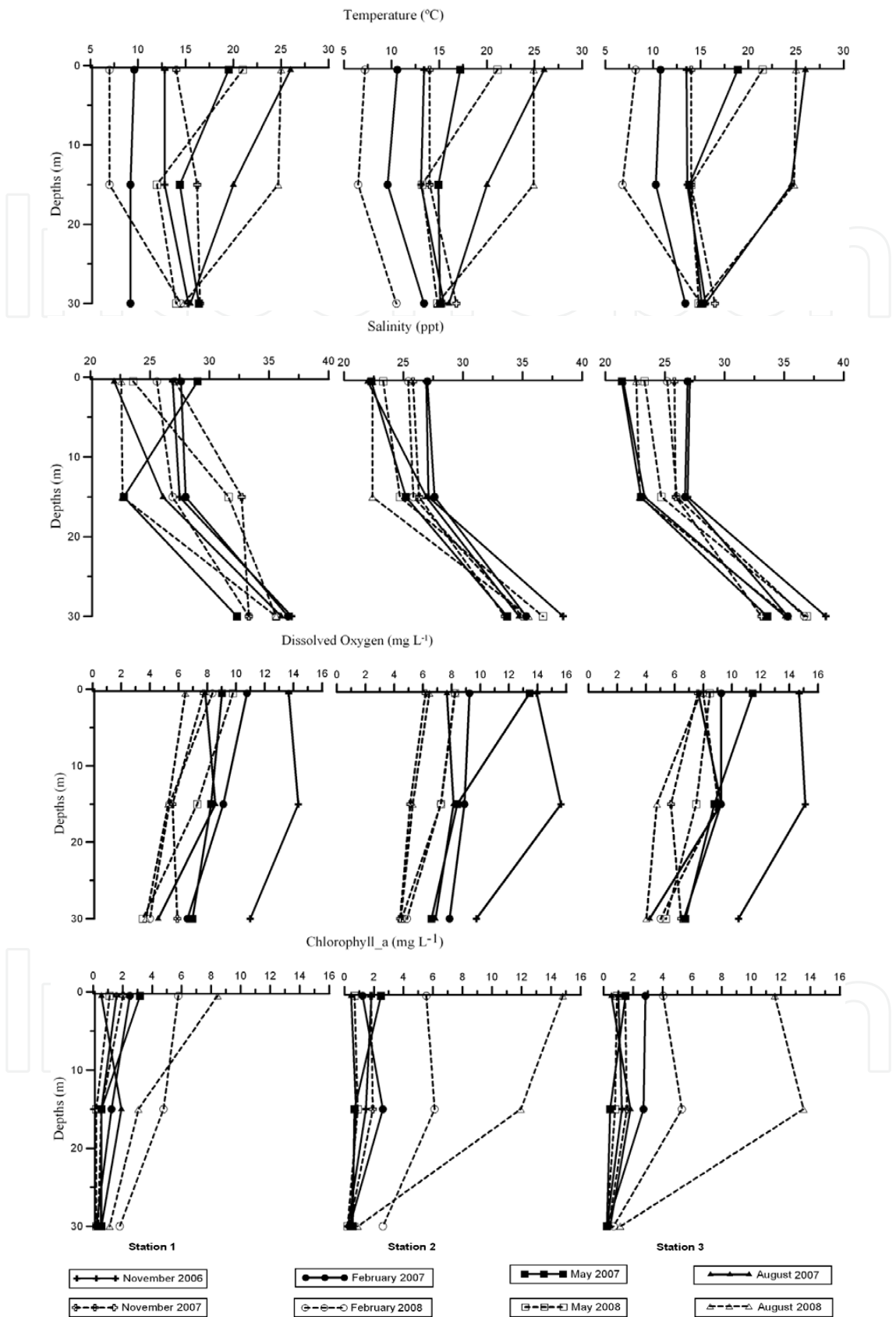


Fig. 2. Vertical variations of temperature (°C), salinity (ppt), dissolved oxygen (DO, mg L<sup>-1</sup>) and chlorophyll *a* (µg L<sup>-1</sup>) along the water column in the Gulf of Bandırma.



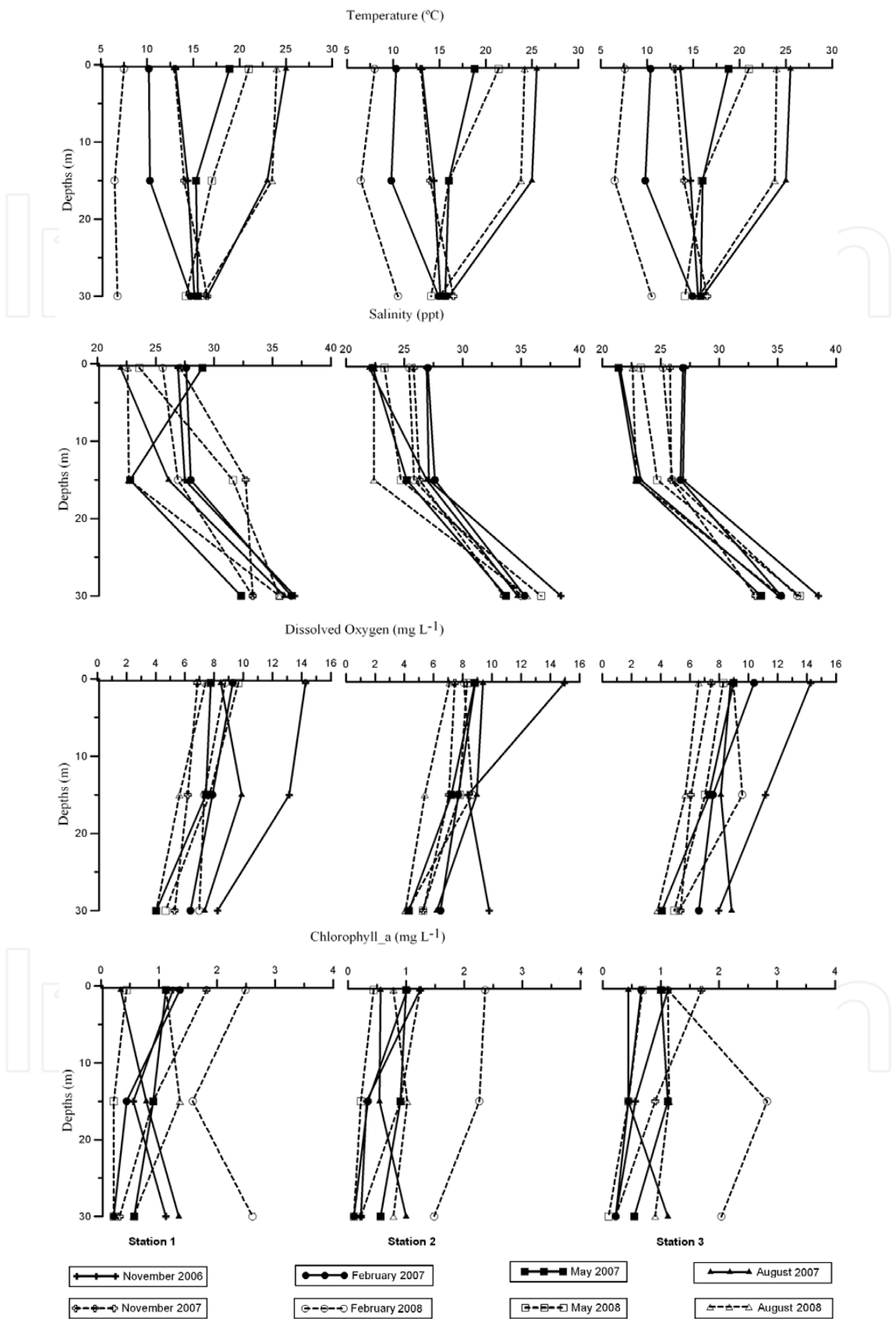


Fig. 3. Vertical variations of temperature (°C), salinity (ppt), dissolved oxygen (DO, mg L<sup>-1</sup>) and chlorophyll *a* (μg L<sup>-1</sup>) along the water column in the Gulf of Erdek.

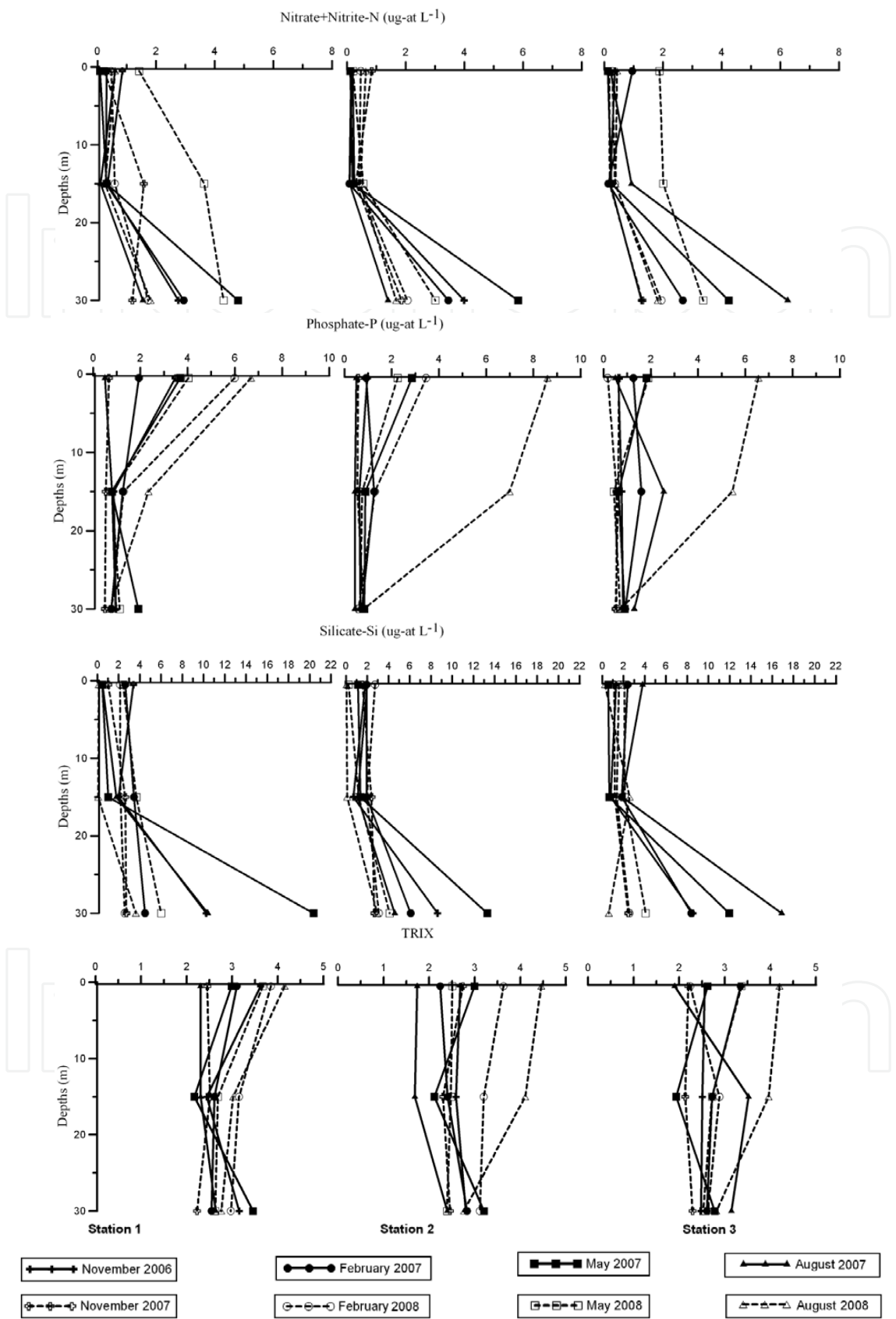


Fig. 4. Vertical variations of nutrient and TRIX index values along the water column in the Gulf of Bandırma.

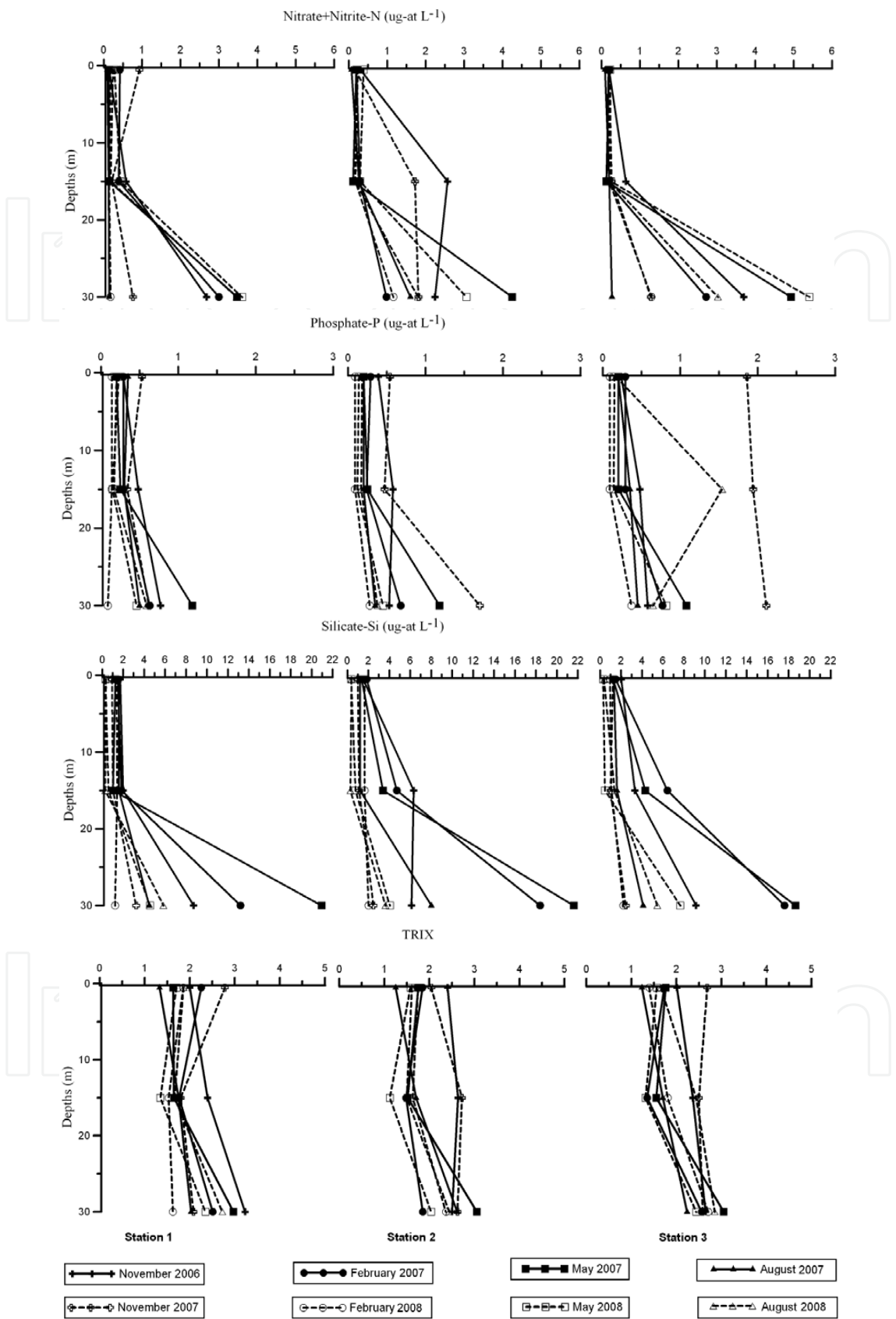


Fig. 5. Vertical variations of nutrient and TRIX index values along the water column in the Gulf of Erdek.

While the Trophic Index (TRIX) value for the Gulf of Erdek was determined to range between 1.12 and 3.23, it ranged between 1.68 and 4.46 for the Gulf of Bandırma (Figs. 4, 5). In addition, an increase was observed in TRIX values with the increase in concentrations of phosphorus and chlorophyll *a* in the last season (August 2008) of the second sampling period in the Gulf of Bandırma.

The results of Spearman’s rank order correlation were employed to explain the relationship among the ecological parameters in the gulfs (Table 2, 3). The nutrients were negatively correlated to dissolved oxygen, but positively to salinity except phosphorus in the Gulf of Bandırma. Also, chlorophyll *a* was negatively correlated with N and Si in the gulfs, however it was positively correlated with P in the Gulf of Bandırma and negatively in the Gulf of Erdek.

	Dissolved oxygen	Temperature	Salinity	Chlorophyll <i>a</i>	Nitrogen	Phosphorus	Silica
Temperature	-,190						
Salinity	-.274**	-.279**					
Chlorophyll <i>a</i>	,139	-,132	-.545**				
Nitrogen	-.482**	,020	.604**	-.521**			
Phosphorus	,170	,106	-.238*	.443**	-,055		
Silica	-.247*	-,175	.706**	-.579**	.699**	-,106	
TRIX	,022	-,043	-,022	.331**	.355**	.640**	,118

Table 2. Spearman’s rank-correlation matrix (*r<sub>s</sub>*) to correlate among ecological variables in the Gulf of Bandırma (\*\* *P*<0.01, \* *P*<0.05, n=72)

	Dissolved oxygen	Temperature	Salinity	Chlorophyll <i>a</i>	Nitrogen	Phosphorus	Silica
Temperature	-,071						
Salinity	-.390**	-.360**					
Chlorophyll <i>a</i>	,151	-.335**	-.280**				
Nitrogen	-.455**	-,117	.675**	-.448**			
Phosphorus	-.397**	,005	.625**	-.345**	.593**		
Silica	-.266*	-.216*	.751**	-.336**	.525**	.618**	
TRIX	-.365**	-.206*	.653**	,000	.745**	.807**	.551**

Table 3. Spearman’s rank-correlation matrix (*r<sub>s</sub>*) to correlate among ecological variables in the Gulf of Erdek (\*\* *P*<0.01, \* *P*<0.05, n=72)

The Bray-Curtis similarity index did not show significant differences at the sampling stations according to ecological parameters. Sampling stations in the gulfs were approximately 91 % similar to each other (Fig. 6).

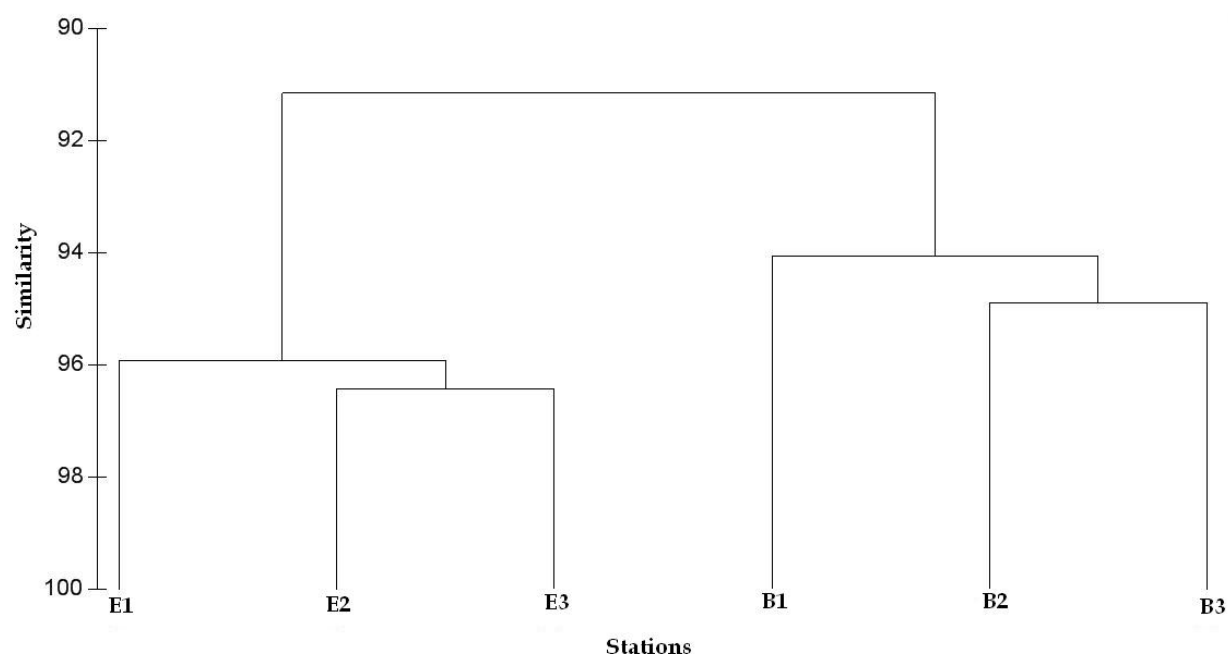


Fig. 6. Bray-Curtis similarity dendrogram of the sampling stations in the Gulfs of Bandırma and Erdek.

#### 4. Discussion

The chemical oceanography of the Marmara Sea is remarkably affected by the Black Sea and the Aegean Sea, and the basin includes two different masses. In this study, the highest temperature values were measured at the depth of 0.5 m in August 2007 in both gulfs with similar characteristics. Especially, the variations of temperatures in surface water showed typically seasonal trend and this was caused by the effect of light and the contact of this layer with the atmosphere. While lower values were measured in the lower layer water compared to the upper in spring and summer, temperature values increased in correlation with the increase in depth in autumn and winter. The increase in temperature at the depth of 30 m during cold periods indicates the effect of the Mediterranean waters. Especially, a sharp decrease was detected in water temperature after the depth of 15 m in August in 2007 and 2008 during all sampling periods in the both gulfs. It was found that less saline water from the Black Sea via the Bosphorus was effective at the depths that were close to the surface and salinity was noted to increase from the surface to the bottom, reaching its highest value at the depth of 30 m due to the Mediterranean current. After 15 m, a sudden increase in salinity was remarkable, which indicates the presence of a halocline layer. Besides, in gulfs salinity values changed seasonally throughout the water column at Station 1, which is an inner one while seasonal changes were more stable until the depth of 15 m at Station 2 and 3 and the values showed sudden increases after this depth.

Rather high oxygen concentrations were observed in the upper water, probably coinciding with the maximum of the photosynthetic activity. A decrease was observed in dissolved oxygen values generally from the surface to the bottom along the water column. This was due to excessive oxygen consumption during the decomposition of detritus, which was produced as a consequence of primary production in the upper layer and biochemical



reactions occurring in the deeper layer. Excessive bacterial and animal activity due to increased phytoplankton biomass and high organic loads in eutrophic systems can lead to oxygen depletion (Karydis, 2009). This decrease in the water column was in accordance with the result of the previous review study (Yılmaz, 2002). The most remarkable period in terms of seasonal changes in oxygen was November 2006 in both gulfs. Considering the other sampling periods, the highest dissolved oxygen values were recorded at all depths in this sampling period. The fate and behavior of DO is of critical importance to marine organisms in determining the severity of adverse impacts (Best et al., 2007). When the DO falls below 5 mg L<sup>-1</sup>, sensitive species of fish and invertebrates can be negatively impacted, and at the DO levels below 2.5 mg L<sup>-1</sup> most fish are negatively impacted (Frodge et al., 1990). Best et al. (2007) provided DO thresholds in accordance with 5 ecological categories in the European Water Framework Directive ( $\geq 5.7$  mg L<sup>-1</sup> High;  $\geq 4.0 < 5.7$  mg L<sup>-1</sup> Good;  $\geq 2.4 < 4.0$  mg L<sup>-1</sup> Moderate;  $\geq 1.6 < 2.4$  mg L<sup>-1</sup> Poor;  $< 1.6$  mg L<sup>-1</sup> Bad). In our study, high and good quality status were detected in both gulfs and moderate quality status were only detected at the depth of 30 m at Station 1 in May and August 2008 in the Gulf of Bandırma and at Station 3 in August 2008 in the Gulf of Erdek. Especially, salinity at 30 m, which increase with the effect of the Mediterranean waters, showed a negative correlation with DO and water quality is moderate at this depth according the DO levels. The main physical factors affecting the concentration of oxygen in the marine environment are temperature and salinity: DO solubility decreasing with increasing temperature and salinity (Best et al., 2007). Negative correlation was found between DO and salinity in the present study ( $p < 0.01$ ). Although pollution has clearly increased in last 30 years in the upper water of the Marmara Sea, dissolved oxygen values in the deeper layer have not changed compared to the values measured in 1970s (Tuğrul et al., 2000).

Chlorophyll *a* production and nutrient availability are closely associated with eutrophication (Nixon, 1995; Kitsiou & Karydis, 2001). Chlorophyll *a* distribution depends on hydro-chemical conditions, namely nutrient availability, temperature changes, light conditions, water turbulence etc. (Lakkis et al., 2003; Nikolaidis et al., 2006 a, b). In this study, the highest chlorophyll *a* values were generally determined in winter period in both gulfs and P/Chl *a* ratio was low in the upper layer due to the increase of chlorophyll *a* value depending on phytoplankton activity and the use of phosphorus by these organisms; however, chlorophyll *a* showed excessive increase only in summer (August 2008) in the Gulf of Bandırma. Especially a serious environmental problem was observed in 2008 in the whole Marmara Sea. In recent studies, it was stated that mucilage formation, which was observed mainly due to excretory activity of some diatoms together with bacteria, the dinoflagellate *Gonyaulax fragilis*, the presence of sharp pycnocline and thermocline caused by the two-layered water system of the Marmara Sea in 2008; besides, which the weather conditions and the status of currents during that time effected this formation (Tüfekçi et al., 2010; Balkis et al., 2011). During the mucilage formation chlorophyll *a* values changed between 0.1-22 µg L<sup>-1</sup> in these studies. According to the study by Ignatiades (2005), the limits of average concentration in chlorophyll *a* are  $< 0.5$  µg L<sup>-1</sup> for oligotrophic, 0.5-1.0 µg L<sup>-1</sup> for mesotrophic and  $> 1.0$  µg L<sup>-1</sup> for eutrophic waters. According to chlorophyll *a* results obtained from both gulfs, the gulfs showed mesotrophic conditions in some periods and eutrophic, hyper-eutrophic (during the mucilage formation event) conditions in others.

Fiocca et al. (1996) reported that the availability of dissolved inorganic nitrogen and dissolved inorganic phosphorus leads to a seasonal change in N/P ratio, high in winter and low in summer. In the euphotic zone, nutrients, especially nitrate+nitrite-N and silicate-Si, are practically depleted by the phytoplankton uptake. In the Marmara Sea, the highest abundance of phytoplankton was recorded in the surface water (0.5-5 m) in recent comprehensive studies (Balkıs, 2003; Deniz & Taş, 2009; Tüfekçi et al., 2010; Taş et al., 2011). The highest nutrient values were recorded generally in the bottom layer where there was aggregation. During the study, positive correlations ( $p < 0.01$ ) of nitrogen and silicate were detected with salinity, which increased with depth. The strong positive correlation ( $p < 0.01$ ) between nitrogen, phosphate and silicate in the Gulf of Erdek and between nitrogen and silicate in the Gulf of Bandırma might indicate that these nutrients come from the same sources into the water column. Especially, the increase in the amount of nitrogen and silica at the depth of 30 m is remarkable since these elements are produced by the bacterial decomposition of the organic substances aggregating at the bottom.

Smith (1984) mentioned that nitrogen budget in the ocean was associated with air-water interaction such as  $N_2$  fixation, losses of fixed nitrogen, or sediment back to gaseous form but that it depends on availability of phosphorus because phosphorus is not exchanged between the ocean and atmosphere as nitrogen. In both gulfs, there was negative correlation ( $p < 0.01$ ) between chlorophyll *a* and nutrients except for the positive correlation ( $p < 0.01$ ) between chlorophyll *a* and phosphorus in the Gulf of Bandırma (Tables 2, 3). It is known that eutrophication variables such as nutrient and chlorophyll *a* do not seem to follow a linear relationship (Karydis, 2009). Interestingly, there was a negative correlation ( $p < 0.05$ ) between salinity and phosphate in the Gulf of Bandırma and positive correlation ( $p < 0.01$ ) in the Gulf of Erdek. The inverse relationship between phosphate and salinity occurs with increasing of evaporation, which depends on temperature while remain nitrogen is at low level concentrations in the gulf (Smith, 1984). Actually, the positive correlation ( $p < 0.01$ ) between phosphate and salinity, which increased with depth indicates the source of phosphate in the water column in the Gulf of Erdek. Smith (1984) argued that the sediments could be reliable records for net nitrogen and phosphorus accumulation in the bays, which have very slow water turnover. Generally, nutrients are depleted by phytoplankton at the points where the light reaches while it increases in direct proportion to depth. The negatively correlated relationships between chlorophyll *a* and nutrients might indicate that nutrients are controlled by primary producers in the short term (Pérez-Ruzafa et al., 2005). In terms of phosphorus inputs, the significant positive relationships between phosphorus and chlorophyll *a* might indicate that the Gulf of Bandırma has not reached the saturation level, which has an enhanced effect on primary productivity. Jaanus (2003) asserted that phosphorus was more important on primary production in eutrophied coastal areas rather than nitrogen when a positive correlation between phosphorus and chlorophyll *a* was detected. On the other hand, the significant negative relationship between nutrients and chlorophyll *a* probably indicates that these nutrients have excessive concentrations, which have a restricted effect on primary production with regard to phosphorus in the Gulf of Bandırma.

Many authors are of the opinion that it is useful to look at the N/Si/P ratios in various parts of the ocean, and that only certain ratios are favorable for bioproductivity. It is known that P stress is common in freshwater systems, whereas N stress is found in marine systems (Ryther & Dunstan, 1971). The nitrogen limitation of phytoplankton growth is common in coastal systems (Nixon, 1986). Redfield et al. (1963) mentioned a C/N/P ratio of 106/16/1

ratio among the elements of sea water. If N/P ratios are below the Redfield value of 16/1, N is limiting nutrient (Stefansson et al., 1963). In the coastal waters of the Gulfs of Bandırma and Erdek, the atomic ratio of N/P was lower than the Redfield ratio of 16, and N was limiting nutrient. The increase in the N/P ratio was remarkable in lower layers in comparison to the surface water, which showed that phosphorus increased in proportion to nitrogen in the surface water while nitrogen increased in proportion to phosphorus in lower layers. In addition, the reason for lower values of N/P ratio in summer months is the limiting effect of nitrogen (Marcovecchio et al., 2006) and in the eutrophic areas, nitrogen might be a significant growth-limiting factor under the conditions, which have high total phosphorus concentration and low total N/P ratio (Attayde & Bozelli, 1999). Diatom growth in marine waters is likely to be limited by dissolved silica when the N/Si ratios are above 1/1 (Roberts et al., 2003). During the study period, the N/Si ratios were low ( $<1$ ), and this indicates that silicate is not a limiting factor, especially for the growth of diatoms. In the studies conducted in the Marmara Sea, it was reported that dinoflagellates and diatoms constitute most of the plankton population, which supports our finding (Balkıs, 2003; Deniz & Taş, 2009; Tüfekçi et al., 2010; Balkıs et al., 2011). It is known that especially diatoms show an excessive increase in summer and spring (Balkıs, 2003; Deniz & Taş, 2009).

The Secchi disk depth for oligotrophic waters varies from 20 to 40 m (Ignatiades et al., 1995). Secchi disk depth detected between 10 and 20 m characterizes mesotrophic conditions whereas it is less than 10 m for eutrophic waters (Ignatiades et al., 1995). The lowest-highest Secchi range recorded in this study is 4.5-16 m. The values measured in 2008 are lower than those recorded in the previous year. Especially in winter when environmental inputs are intense lower values were recorded. In addition, intense vertical mixtures also caused turbidity in this period.

Trophic condition of vast marine areas, like the Mediterranean, varies considerably from region to region and within regions (Vollenweider et al., 1996). Vollenweider et al. (1998) calculated TRIX mean values as 3.37-5.60 for the Adriatic Sea. Moncheva et al. (2001) detected that TRIX index values varied from 5.0 to 6.0 in the Thermaikos Gulf of the northern Aegean Sea, and the lowest values were recorded in summer. In addition, the index was recorded between 1.9-4.7 in Kalamitsi on the east coasts of the central Ionian Sea (Nikolaïdis et al., 2008), 6.90-7.70 in southern Black Sea (Baytut et al., 2010), 0.86-2.98 in the Edremit Bay of the Aegean Sea (Balkıs & Balcı, 2010). Calculated TRIX values were slightly lower than expected because  $\text{NH}_4$  was not measured in this study and used in the original formula. Low TRIX values, as defined in this paper, indicate poorly productive waters corresponding to high water quality in the Gulfs of Erdek and Bandırma. On the other hand, according to chlorophyll *a* results the environment generally showed mesotrophic-eutrophic conditions. The chlorophyll *a* scale used above (Ignatiades, 2005) is the one suggested for the Aegean Sea. The Marmara Sea, different from the Aegean Sea, is an inland sea and has a two-layered water system. The calculated TRIX values without  $\text{NH}_4$  could be caused to obtain low values. Especially the upper layer waters are under the effect of the waters of Black Sea, which has intense river inputs. Therefore, in order to determine the water quality of the environment not only physical and chemical studies but also biological studies that will show the organism communities in the environment and their abundance should be conducted. This study showed the current state of water quality in both gulfs and can be used as a main source in determining possible changes in these gulfs in future. Moreover, effective wastewater management including nutrient control may be required for an effective pollution prevention program in these regions.

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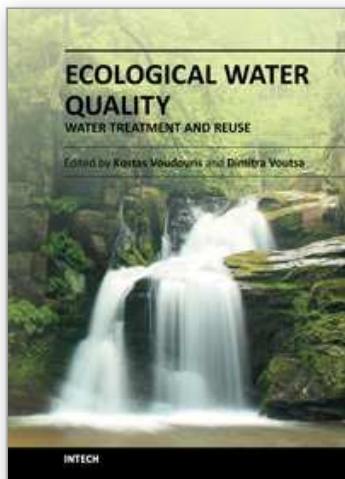


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This book attempts to cover various issues of water quality in the fields of Hydroecology and Hydrobiology and present various Water Treatment Technologies. Sustainable choices of water use that prevent water quality problems aiming at the protection of available water resources and the enhancement of the aquatic ecosystems should be our main target.

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