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Nutrition Profile of the Sea of Marmara Between Years 2010 and 2013

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Abstract: In order to determine the nutrition load in the Sea of Marmara, sampling was realised on appointed 25 stations, at standard vertical sections from surface to deepest point of the station, bi-annually between 2010 and 2013. NO_2–N, NO_3–N, NH_4–N, and PO_4–P were analysed from unfiltered water samples; in addition, some physicochemical parameters that play important roles, such as salinity, temperature, dissolved oxygen, and pH, were measured for each station. This study reports on nutrients load in the Sea of Marmara for a preliminary assessment of the status of these nutrients and a brief discussion about the unique oceanographic status of the Sea of Marmara.

Keywords: Sea of Marmara; nutrient; pycnocline; thermocline; halocline; pollution.

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INTRODUCTION

The Sea of Marmara and Turkish Straits extend from the Aegean Sea to the Black Sea trough the Dardanelles (60 km), Sea of Marmara (210 km), and Bosphorus (31 km). The total length of the system is approximately 300 km, with a maximum depth of 1273 m **(1)**.

Because of huge density differences between the waters of the Mediterranean and the Black Sea, occurs a two-layer current system along the Sea of Marmara and Turkish Straits (TS) flowing in opposite direction.

The watermasses of the Black Sea are entirely different from those of the Mediterranean Sea originated watermasses. In the Black Sea precipitation and runoff exceeds evaporation, for which reason a surface layer of relatively low salinity and correspondingly low density is present.

Owing to the distribution of density, the surface waters of Black Sea flow through the Bosphorus and the Dardanelles into the Aegean Sea basin and Mediterranean Sea originated water flows in along the bottom. The outflow from the Black Sea basin is a function of its water budget and carries runoff from the large rivers and surface waters during into the Black Sea **(2)**.

Intensive mixing takes place mainly along the Bosphorus as well as in the other parts of the straits and Sea of Marmara. The salinity of the inflowing Mediterranean Sea originated watermass which is over 38.50 ‰ at the entrance of the Dardanelles strait decreases slowly with the distance travelled in the Sea of Marmara down to 29 ‰, where the bottom current enters the Black Sea at the Northern end of the Bosphorus. At the same time, the salinity of the outflowing water is increased from 16 ‰ in origin in the Black Sea to 30 ‰ leaving the Dardanelles **(3)**.

The in- and outflowing water masses are separated by a well-defined transition layer, which oscillates in accordance to the contours of the bottom. This layer of transition also represents the discontinuity layer for temperature and salinity and called thermo-halocline **(4, 5)**.

The exponentially growing pollution since 1980 is the main problem in the Sea of Marmara. All the settled areas around and also in the hinterland of the Sea of Marmara are discharging the wastes using "deep sea discharges" without any treatment directly under the pycnocline–thermocline layer in the Sea of Marmara **(3)**.

In 1980's the Istanbul municipality started a project in contemplation of using the Mediterranean Sea originated upper current as a conveyor for transport and discard the waste water to the Black Sea without any treatment, and applied it despite the countering measurements **(2)**.

Now it is known that the Mediterranean originated undercurrent only reaches 30% to the Black Sea with the most optimistic estimate due to the changes of the salinity stratification of the surface water and the seasonal volumetric fluctuations of the surface currents, the undercurrent does not reach continuously to the Black Sea basin **(3)**.

The role of nutrients in limiting and/or boosting primary production in the sea is widely acknowledged.

Dissolved Nitrite Nitrogen (NO_2-N), Nitrate Nitrogen (NO_3-N), Ammonium Nitrogen (NH_4-N), and Phosphate Phosphorus (PO_4-P) are large and important fractions of marine nutrient pools, especially in euphotic zones. Compounds of nitrogen, and especially those of phosphorus, are major cellular components of organisms **(6)**.

There are no adequate studies of nutrients across the Sea of Marmara. Some of the studies are, with the topics of; "Organic carbon distribution in the surface sediments of the Sea of Marmara and its control by the inflows from adjacent water masses" **(7)**. "Elemental composition of seston and nutrient dynamics in the Sea of Marmara" **(8)**; "Nutrient exchange fluxes between the Aegean and Black Seas through the Marmara Sea" **(9)**, respectively.

During the last four decades, drastic changes have occurred in the Sea of Marmara ecosystem because of anthropogenic pressures. Therefore, this study was designed to monitoring of the seasonal variations in nutrients of this area between years 2010 and 2013 (and ongoing).

MATERIALS AND METHODS

The present study is based on data gathered during survey cruises in the Sea of Marmara waters between 2010 and 2013 and realized biannually as winter and summer seasons measurements on 23 stations (Figure 1).

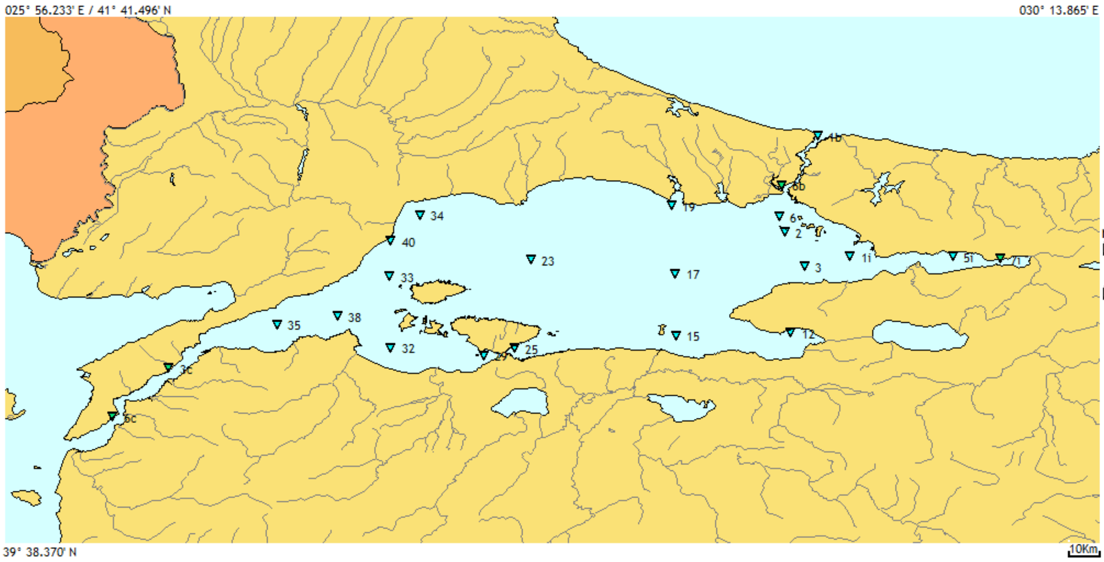


Figure 1. Map with the location of the sampling stations.

Data gathering conducted on winter and summer seasons due to direct effect of temperature and precipitation on the solubility and concentration of nutrients in sea water and also availability of MAREM project stuff.

The network of stations is shown in Figure 1 and locations in Table 1. All 24 stations were observed with the standard depths from 0.5 to 1000 m or less for the bottom.

Table 1. The location table of the stations with maximum depths of the station.

Station N°	Coordinate	Depth	Station N°	Coordinate	Depth
2	40° 50.333' N : 028° 59.733' E	515 m	**32**	40° 23.283' N : 027° 26.950' E	39 m
3	40° 42.383' N : 029° 04.367' E	1000 m	**33**	40° 39.883' N : 027° 26.650' E	138 m
6	40° 53.883' N : 028° 58.350' E	52 m	**34**	40° 54.350' N : 027° 33.783' E	187 m
12	40° 26.750' N : 029° 01.067' E	83 m	**35**	40° 28.750' N : 027° 00.100' E	58 m
15	40° 26.117' N : 028° 33.950' E	53 m	**38**	40° 30.733' N : 027° 14.433' E	65 m
17	40° 40.583' N : 028° 33.900' E	442 m	**3c**	40° 18.517' N : 026° 34.683' E	46 m
19	40° 56.600' N : 028° 33.083' E	59 m	**40**	40° 48.283' N : 027° 26.950' E	997 m
1b	41° 12.817' N : 029° 07.350' E	87 m	**5i**	40° 44.633' N : 029° 39.133' E	121 m
1i	40° 44.717' N : 029° 15.050' E	380 m	**6b**	41° 01.283' N : 028° 58.950' E	39 m
23	40° 43.933' N : 027° 59.950' E	850 m	**6c**	40° 07.083' N : 026° 21.483' E	86 m
25	40° 23.167' N : 027° 56.100' E	33 m	**7i**	40° 44.050' N : 029° 50.283' E	32 m
29	40° 21.500' N : 027° 48.783' E	33 m			

The chemical parameters were measured by collecting seawater samples with Niskin bottles, and analysed using a Shimadzu spectrophotometer UV-240 in the laboratory on board. NO_2–N, NO_3–N, NH_4–N, and PO_4–P were analysed from unfiltered water samples, according to Standard Methods for the Examination of Water and Wastewater **(10)**.

All oceanographic parameters were measured *in situ* with a CTD YSI 6600 V2 multi-parameter data probe and MIDAS ECM with additional probes (pH and Dissolved Oxygen) along the water column with 1 sec duration (approximately 10 cm intervals) from the surface (0.5 m) to the deepest section of the station.

All the data are stored in MAREM database and processed with the HIDRO-QL software. (10)

Remarks: The measurements in highly polluted areas, such as Golden Horn and the tip of the İzmit Bay, are present in hydrographical tables but that values and corresponding stations are left out of accounts by mean maximum and minimum values to characterize the water masses.

RESULTS

Temperature

Table 2. Average long-term temperature distribution/fluctuation of the whole Sea of Marmara area incl. Turkish Straits, during summer seasons, in depth basis between years 2010 and 2013 in the summer seasons.

Beginning Date: **28/02/2010** | Emin: **029° 55.050' E** | Nmin: **37° 13.000' N**
Ending Date: **27/08/2013** | Emax: **026° 07.000' E** | Nmax: **41° 20.000' N**
PARAMETER: **T°C** | PROJECT: **MAREM**

DEPTH. (m)	MIN.	MAX.	DIFF.	QUAN.	MEAN	ST.DEV.	VAR.	SEM.	MEAN COR.	VOL. AV.	VOL. ST.DEV.
0.5	19.59	29.89	10.30	222	26.20	1.785	3.173	0.120	26.20	26.20	1.785
5.0	17.82	29.86	12.04	222	25.07	2.375	5.617	0.159	24.91	25.63	2.173
10.0	14.96	29.81	14.85	215	23.31	3.223	10.342	0.220	21.59	24.87	2.783
25.0	10.97	18.92	7.95	208	14.66	1.621	2.616	0.112	17.09	22.42	5.057
50.0	13.20	18.09	4.89	126	15.72	0.780	0.604	0.069	15.32	21.57	5.234
100.0	14.60	15.73	1.13	43	15.19	0.294	0.084	0.045	15.32	21.31	5.280
250.0	14.41	16.08	1.67	27	15.16	0.442	0.188	0.085	15.16	21.15	5.302
500.0	14.03	16.29	2.26	20	15.12	0.684	0.444	0.153	15.10	21.04	5.316
750.0	14.02	16.05	2.03	13	15.02	0.612	0.346	0.170	14.99	20.97	5.325
1,000.0	14.01	16.11	2.10	6	14.79	0.828	0.571	0.338	14.85	20.93	5.330

(MIN=minimum value; MAX=maximum value; DIFF=difference; QUAN=quantity of measurements; MEAN= mean value; S.DEV=standard deviation; VAR= variance; SEM=standard error of mean; MEAN COR= mean correction; VOL. AV. = volumetric average; VOL. S. DEV. = volumetric standard deviation).

The temperature conditions seem to have the same main characteristics in all the cross-sections (Tables 2-3). This also flows from the longitudinal section. The water temperatures of the upper water mass which is Black Sea-originated water change between 7.9 °C and 29.9 °C, depending on the meteorological conditions. The deeper layers are consequently more homogeneous with respect to the temperature than the upper layers between 10.8°C and 18.2°C with a constant average of 14.2°C, in summer seasons.

Also the temperatures in the winter season of the upper water mass changes between 5.8°C and 16.2°C, depending on the meteorological conditions. The deeper layers are consequently more homogeneous with respect to the temperature than the upper layers between 10.1°C and 16.2°C.

Salinity

The salinity conditions in the Sea of Marmara provide a striking example of the difference between the Black Sea water and the Mediterranean originated water. The transition layer is very prominent, the mean salinity rising about 22.5 ‰ from surface to 35.6 ‰ on 50 m depth (Tables 4-5). The upper layer has an average salinity of about 25 ‰. This water mixture, which is composed of the Black Sea and Mediterranean Sea-originated water, takes place mainly in the turbulent channel of the Bosphorus. The deeper layer is uniform with respect to salinity, varying between 38.5 and 38.8 ‰.

Table 3. Average long-term temperature distribution/fluctuation of the whole Sea of Marmara area incl. Turkish Straits, during winter seasons, in depth basis between years 2010 and 2013 in the winter seasons.

Beginning Date: **28/02/2010**	Emin: **029° 55.050' E**	Nmin: **37° 13.000' N**
Ending Date: **27/08/2013**	Emax: **026° 07.000' E**	Nmax: **41° 20.000' N**
PARAMETER: **T°C**	PROJECT: **MAREM**	

DEPTH. (m)	**MIN.**	**MAX.**	**DIFF.**	**QUAN.**	**MEAN**	**ST.DEV.**	**VAR.**	**SEM.**	**MEAN COR.**	**VOL. AV.**	**VOL. ST.DEV.**
0.5	5.81	10.90	5.09	146	6.81	1.080	1.159	0.089	6.81	6.81	1.080
5.0	5.90	11.10	5.20	146	6.96	1.030	1.054	0.085	7.08	6.89	1.056
10.0	5.90	14.85	8.95	144	7.59	1.871	3.478	0.156	8.20	7.12	1.417
25.0	6.40	15.94	9.54	138	10.68	3.582	12.740	0.305	10.87	7.98	2.628
50.0	10.10	16.15	6.05	98	14.53	1.215	1.462	0.123	13.64	8.93	3.387
100.0	13.00	15.75	2.75	32	14.82	0.853	0.705	0.151	14.61	9.20	3.533
250.0	13.10	14.97	1.87	22	14.27	0.465	0.206	0.099	14.42	9.35	3.587
500.0	13.30	14.85	1.55	16	14.34	0.417	0.163	0.104	14.30	9.46	3.622
750.0	13.30	14.67	1.37	12	14.27	0.387	0.137	0.112	14.27	9.54	3.644
1,000.0	13.20	14.64	1.44	8	14.20	0.470	0.193	0.166	14.22	9.59	3.656

Table 4. Average long-term salinity distribution/fluctuation of whole Sea of Marmara area incl. Turkish Straits, during summer seasons, in depth basis between years 2010 and 2013.

Beginning Date: **28/02/2010**				Emin: **029° 55.050' E**				Nmin: **37° 13.000' N**			
Ending Date: **27/08/2013**				Emax: **026° 07.000' E**				Nmax: **41° 20.000' N**			
PARAMETER: **SAL ‰**				PROJECT: **MAREM**							
DEPTH. (m)	**MIN.**	**MAX.**	**DIFF.**	**QUAN.**	**MEAN**	**ST.DEV.**	**VAR.**	**SEM.**	**MEAN COR.**	**VOL. AV.**	**VOL. ST.DEV.**
0.5	12.70	25.36	12.66	222	20.50	2.439	5.922	0.164	20.50	20.50	2.439
5.0	13.20	26.30	13.10	222	20.84	2.373	5.605	0.159	20.93	20.67	2.410
10.0	13.90	35.89	21.99	215	21.55	2.688	7.189	0.183	24.12	20.96	2.535
25.0	16.79	38.29	21.50	208	32.55	4.592	20.989	0.318	30.78	23.74	5.871
50.0	27.85	40.22	12.37	126	36.47	2.638	6.905	0.235	35.52	25.36	6.995
100.0	31.10	40.05	8.95	43	36.59	2.558	6.393	0.390	36.93	25.82	7.224
250.0	34.80	40.02	5.22	27	38.06	1.327	1.696	0.255	37.84	26.13	7.390
500.0	36.71	40.19	3.48	20	38.65	1.139	1.233	0.255	38.63	26.36	7.515
750.0	37.71	40.49	2.78	13	39.16	1.017	0.955	0.282	39.07	26.52	7.598
1,000.0	38.05	40.73	2.68	6	39.32	1.097	1.003	0.448	39.28	26.59	7.636

Table 5. Average long-term salinity distribution/fluctuation of whole Sea of Marmara area incl. Turkish Straits, during winter seasons, in depth basis between years 2010 and 2013.

Beginning Date: **28/02/2010**				Emin: **029° 55.050' E**				Nmin: **37° 13.000' N**			
Ending Date: **27/08/2013**				Emax: **026° 07.000' E**				Nmax: **41° 20.000' N**			
PARAMETER: **SAL ‰**				PROJECT: **MAREM**							
DEPTH. (m)	**MIN.**	**MAX.**	**DIFF.**	**QUAN.**	**MEAN**	**ST.DEV.**	**VAR.**	**SEM.**	**MEAN COR.**	**VOL. AV.**	**VOL. ST.DEV.**
0.5	13.00	29.70	16.70	146	22.26	3.006	8.974	0.249	22.26	22.26	3.006
5.0	14.07	29.80	15.73	146	23.09	2.867	8.161	0.237	23.20	22.67	2.962
10.0	14.58	34.78	20.20	144	24.36	3.301	10.824	0.275	25.42	23.23	3.175
25.0	20.14	38.46	18.32	138	29.86	5.764	32.983	0.491	29.72	24.82	4.861
50.0	26.57	39.39	12.82	98	34.78	3.782	14.154	0.382	33.34	26.28	5.882
100.0	26.69	38.90	12.21	32	33.96	4.691	21.314	0.829	34.72	26.62	6.047
250.0	32.00	39.30	7.30	22	36.16	2.582	6.366	0.550	35.66	26.91	6.190
500.0	33.73	39.54	5.81	16	36.38	2.033	3.875	0.508	36.52	27.12	6.283
750.0	34.87	39.80	4.93	12	37.16	1.824	3.050	0.527	37.21	27.28	6.362
1,000.0	35.83	39.98	4.15	8	38.13	1.659	2.409	0.587	37.89	27.39	6.427

The striking feature is that the transition layer is not found at the same depth in the different sections of the Sea of Marmara. If we have to divide the water mass of the Sea of Marmara into four parts from east to west, the transition layer is between 10 and 25 m in the first eastern part; and in the next, it is at 25-50 m; in the third quadrant, it is again found at 10-25 m, and finally, in the outermost section the transition layer reaches the surface in the southern part. The middle transition layer lies about 25-50 m and in the northern part between 10 and 25 m.

Dissolved Oxygen

As usual, the upper layer is well oxygenated relative to the deeper layers. The content of dissolved oxygen (DO) decreases from 5.7 mgL^{-1} at 0.5 m to 2.6 mgL^{-1} at about 50 m in summer (Table 6) and from 7.3 mgL^{-1} at 0.5 m to 3.9 mgL^{-1} at about 50 m in winter (Table 7). The decrease is not always regular. One characteristic feature is an intermediate minimum occurring in the western part of the Sea of Marmara. At the entrance of the Dardanelles, there is an intermediate maximum layer at about 125 to 150 m. The DO content of in moving water is slightly higher than elsewhere in the depths of the Sea of Marmara. The effect can be traced along the southern shore.

Table 6. Average long term dissolved oxygen (mg/l) distribution/fluctuation of whole Sea of Marmara area incl. Turkish Straits, during summer seasons, in depth basis between years 2010 and 2013.

Beginning Date: **28/02/2010**				Emin: **029° 55.050' E**				Nmin: **37° 13.000' N**			
Ending Date: **27/08/2013**				Emax: **026° 07.000' E**				Nmax: **41° 20.000' N**			
PARAMETER: **DO (mg/l)**				PROJECT: **MAREM**							
DEPTH. (m)	**MIN.**	**MAX.**	**DIFF.**	**QUAN.**	**MEAN**	**ST.DEV.**	**VAR.**	**SEM.**	**MEAN COR.**	**VOL. AV.**	**VOL. ST.DEV.**
0.5	2.46	8.89	6.43	222	5.68	1.203	1.441	0.081	5.68	5.68	1.203
5.0	2.25	7.77	5.52	222	5.10	1.128	1.267	0.076	5.15	5.39	1.201
10.0	1.35	7.00	5.65	215	4.71	1.057	1.111	0.072	4.52	5.16	1.198
25.0	0.80	7.22	6.42	208	3.56	1.198	1.429	0.083	3.61	4.78	1.380
50.0	0.14	6.49	6.35	126	2.62	1.371	1.866	0.122	2.61	4.51	1.555
100.0	0.04	4.36	4.32	43	1.64	0.974	0.927	0.149	1.76	4.39	1.638
250.0	0.15	3.47	3.32	27	1.15	0.794	0.607	0.153	1.20	4.30	1.700
500.0	0.02	3.13	3.11	20	0.88	0.891	0.755	0.199	0.97	4.24	1.750
750.0	0.09	3.01	2.92	13	0.97	1.002	0.927	0.278	0.80	4.20	1.778
1,000.0	0.03	1.55	1.52	6	0.36	0.592	0.292	0.242	0.51	4.18	1.796

Table 7. Average long term dissolved oxygen (mg/L) distribution/fluctuation of whole Sea of Marmara area incl. Turkish Straits, during winter seasons, in depth basis between years 2010 and 2013.

Beginning Date: **28/02/2010**				Emin: **029° 55.050' E**				Nmin: **37° 13.000' N**			
Ending Date: **27/08/2013**				Emax: **026° 07.000' E**				Nmax: **41° 20.000' N**			
PARAMETER: **DO (mg/l)**				PROJECT: **MAREM**							
DEPTH. (m)	**MIN.**	**MAX.**	**DIFF.**	**QUAN.**	**MEAN**	**ST.DEV.**	**VAR.**	**SEM.**	**MEAN COR.**	**VOL. AV.**	**VOL. ST.DEV.**
0.5	4.41	9.77	5.36	146	7.52	0.837	0.695	0.069	7.52	7.52	0.837
5.0	3.50	8.90	5.40	146	7.11	0.977	0.949	0.081	7.09	7.31	0.930
10.0	3.10	8.60	5.50	144	6.61	1.096	1.194	0.091	6.41	7.08	1.041
25.0	1.70	7.64	5.94	138	5.32	1.384	1.900	0.118	5.34	6.66	1.361
50.0	1.10	6.66	5.56	98	4.11	1.194	1.411	0.121	4.29	6.29	1.611
100.0	2.02	5.22	3.20	32	3.61	0.910	0.803	0.161	3.40	6.16	1.681
250.0	0.80	4.04	3.24	22	2.27	0.800	0.611	0.171	2.52	6.05	1.790
500.0	1.01	3.81	2.80	16	1.94	0.975	0.891	0.244	1.93	5.96	1.873
750.0	0.80	3.12	2.32	12	1.57	0.882	0.712	0.255	1.54	5.89	1.941
1,000.0	0.38	2.65	2.27	8	1.06	0.808	0.571	0.286	1.19	5.84	1.994

pH Values

pH range, compared to the long-term data of the horizontal and vertical directions, seems to be constant. The average pH mean value ranges from 7.70 to the 7.75 in the upper layer with an average of 7.67, and in the layer under the halocline (approx. 30 m) ranges between 7.69 and 8.05 with an average pH of 7.8 (Table 8-9).

Usually, the alkaline ratios increase direct proportionally depending depth level in the Sea of Marmara. The relative acidity levels are found in the bays mainly with anthropogenic activity in the Sea of Marmara.

Nutrients

The seasonal variability of all the nitrogen compounds was somewhat chargeable, by the presence of many concentration peaks the highest concentrations of nitrate (910.00 μgL^{-1}) in the Sea of Marmara were observed in the winter period at the year of 2010 at 10 metres depth (Table 10), which is explained by the increase in coastal water influx due to rains and decrease in phytoplankton activity.

The observed concentrations of nitrate generally decreased in winter periods and increased in summer with a regular fluctuation in Sea of Marmara. While in winter, concentrations were significantly higher, and their variability was of a stepwise nature. A relatively small increase (up to 63.00 μgL^{-1}) in concentration was observed in 2010. A maximum nitrate nitrogen value was reached at the end of 2010 winter study during stepwise increases in concentrations in the spring and at the end of the summer-to-fall period concentrations of this variable temporarily increased to 395.00 μgL^{-1} (Table. 10).

These concentrations are abnormal even for nearshore surface waters and can be related only to shore outflow.

The type of nitrite variation values (NO_2) was more or less similar to a period in Sea of Marmara. The maximum concentrations of nitrites in Sea of Marmara prove the active mineralization of organic matter.

Table 8. Average long-term pH distribution/fluctuation of whole Sea of Marmara area incl. Turkish Straits, during summer, in depth basis between years 2010 and 2013.

Beginning Date: **28/02/2010**				Emin: **029° 55.050' E**				Nmin: **37° 13.000' N**			
Ending Date: **27/08/2013**				Emax: **026° 07.000' E**				Nmax: **41° 20.000' N**			
PARAMETER: **pH**				PROJECT: **MAREM**							
DEPTH. (m)	**MIN.**	**MAX.**	**DIFF.**	**QUAN.**	**MEAN**	**ST.DEV.**	**VAR.**	**SEM.**	**MEAN COR.**	**VOL. AV.**	**VOL. ST.DEV.**
0.5	6.61	8.99	2.38	222	8.00	0.374	0.139	0.025	8.00	8.00	0.374
5.0	6.51	8.91	2.40	222	8.04	0.363	0.131	0.024	8.03	8.02	0.369
10.0	6.53	8.91	2.38	215	8.03	0.356	0.126	0.024	8.02	8.02	0.364
25.0	6.75	8.94	2.19	208	8.00	0.307	0.094	0.021	8.01	8.02	0.351
50.0	6.80	8.75	1.95	126	8.01	0.319	0.101	0.028	7.98	8.02	0.347
100.0	6.83	8.46	1.63	43	7.88	0.292	0.084	0.045	7.90	8.01	0.346
250.0	7.24	8.42	1.18	27	7.83	0.303	0.088	0.058	7.83	8.01	0.346
500.0	6.44	8.49	2.05	20	7.77	0.529	0.266	0.118	7.82	8.00	0.352
750.0	7.22	8.25	1.03	13	7.89	0.312	0.090	0.087	7.84	8.00	0.351
1,000.0	6.83	8.11	1.28	6	7.80	0.488	0.199	0.199	7.82	8.00	0.352

Table 9. Average long-term pH distribution/fluctuation of whole Sea of Marmara area incl. Turkish Straits, during winter, in depth basis between years 2010 and 2013.

Beginning Date: **28/02/2010** | Emin: **029° 55.050' E** | Nmin: **37° 13.000' N**

Ending Date: **27/08/2013** | Emax: **026° 07.000' E** | Nmax: **41° 20.000' N**

PARAMETER: **pH** | PROJECT: **MAREM**

DEPTH. (m)	MIN.	MAX.	DIFF.	QUAN.	MEAN	ST.DEV.	VAR.	SEM.	MEAN COR.	VOL. AV.	VOL. ST.DEV.
0.5	6.01	8.80	2.79	146	7.30	0.645	0.413	0.053	7.30	7.30	0.645
5.0	6.20	8.80	2.60	146	7.35	0.599	0.356	0.050	7.35	7.33	0.622
10.0	6.14	8.81	2.67	144	7.39	0.529	0.278	0.044	7.38	7.35	0.593
25.0	6.31	8.10	1.79	138	7.39	0.440	0.192	0.037	7.40	7.36	0.560
50.0	6.45	8.18	1.73	98	7.45	0.433	0.186	0.044	7.43	7.37	0.544
100.0	6.60	8.00	1.40	32	7.44	0.390	0.148	0.069	7.54	7.37	0.538
250.0	7.04	8.38	1.34	22	7.82	0.334	0.106	0.071	7.77	7.39	0.538
500.0	7.09	8.92	1.83	16	8.01	0.504	0.238	0.126	8.00	7.40	0.545
750.0	7.14	9.02	1.88	12	8.17	0.601	0.331	0.173	8.16	7.41	0.553
1,000.0	7.71	9.15	1.44	8	8.27	0.641	0.359	0.227	8.25	7.42	0.561

Table 10. Nutrients' fluctuations based on years and periods 2010 and 2013.

	NO_2^- (µg.L^{-1})		NO_3^- (µg.L^{-1})		PO_4 – P (µg.L^{-1})		NH_3 – N (µg.L^{-1})	
	Min.	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
2010 Winter	1.00 station no:24 0.5 m	8.00 station no:23 0.5 m	63.00 station no:22 10 m	910.00 station no:33 10 m	118.00 station no:19 0.5 m	980.00 station no:1b 0.5 m	30.00 station no:24 0.5 m	830.00 station no:19 0.5 m
2010 Summer	0.04 station no:33 0.5 m	12.10 station no:23 0.5 m	136.00 station no:2 100 m	395.00 station no:6b 30 m	483.00 station no:1b 20 m	525.00 station no:1b 0.5 m	23.20 station no:17 10 m	628.00 station no:33 100 m
2011 Winter	0.41 station no:1b 0.5 m	28.80 station no:40 0.5 m	161.00 station no:6i 10 m	326.00 station no:15 0.5 m	300.00 station no:17 0.5 m	600.00 station no:8 0.5 m	100.00 station no:1i 10 m	391.00 station no:15 10 m
2011 Summer	0.28 station no:3i 0.5 m	21.38 station no:1i 300 m	193.90 station no:23 0.5 m	817.70 station no:1b 50 m	11.160 station no:40 0.5 m	234.70 station no:2 0.5 m	274.20 station no:1b 0.5 m	908.80 station no:5i 50 m
2012 Winter	0.04 station no:19 0.5 m	21.30 station no:12 10 m	41.83 station no:6c 10 m	384.68 station no:23 50 m	39.13 station no:29 0.5 m	285.38 station no:33 10 m	14.568 station no:3 500 m	477.82 station no:23 400 m
2012 Summer	0.04 station no:23 0.5 m	6.86 station no:1i 0.5 m	131.42 station no:40 1000 m	881.42 station no:3 100 m	37.43 station no:40 1000 m	268.42 station no:6 10 m	10.00 station no:40 1000 m	751.80 station no:6c 50 m
2013 Winter	0.04 station no:2 0.5 m	13.377 station no:23 400 m	186.46 station no:23 10 m	665.83 station no:1b 50 m	119.40 station no:17 0.5 m	1560.20 station no:23 10 m	26.816 station no:2 50 m	2413.40 station no:38 10 m
2013 Summer	0.04 station no:19 0.5 m	4.072 station no:1b 50 m	131.42 station no:40 900 m	603.44 station no:6b 0.5 m	99.735 station no:40 900 m	418.37 station no:38 0.5 m	108.60 station no:23 0.5 m	2309.60 station no:38 10 m

Ammoniacal nitrogen was characterized by a similar variability (the winter maximum gradually gives way to the summer decrease in concentrations). The annual trend of ammoniacal nitrogen had no significant changes (Table. 10).

Especially during the winter period, when consumption of phosphate was insignificant, the concentration fluctuated to 37.43 μgL^{-1} (Table. 10). Exhaustion of phosphate in the summer period in 2010-2013 coincides with such seasonal features as a lack of precipitation and absence of intensive mixing. Only by the end of the summer period did the concentration of phosphates see an increase. While the seasonal trend in Sea of Marmara consisted of many concentration peaks, they are more pronounced in the Sea of Marmara. Phosphate background was significantly higher here as well, most likely a result of a large quantity of organics in the intake of the Sea of Marmara and hindered water exchange.

Analysis of the inter-annual distribution of phosphorus shows a gradual increase in concentrations. Abnormal peaks (525.00 μgL^{-1}) of phosphorus were observed in 2010 summer study. In the same periods, the contents of nitrate (395.00 μgL^{-1}) and ammonia (628.00 μgL^{-1}) were very high. Such abnormal peaks are most likely the result of waste water that pollutes the Sea of Marmara inflow, since at this time meteorological cataclysms take place, *e.g.* local floods and waterspouts damaging the coast. A comparison of phosphate concentrations in the summer period in 2010-2013 suggests a general tendency towards an increase in phosphate concentration from year to year (Table. 11).

Table 11. Mean Nutrient values basis on years and seasons between 2010 and 2013.

	NO_2^- ($\mu g.L^{-1}$)	**NO_3^- ($\mu g.L^{-1}$)**	**PO_4 – P ($\mu g.L^{-1}$)**	**NH_3 – N ($\mu g.L^{-1}$)**
2010 Winter	2,07	518,42	516,67	350,56
2010 Summer	1,96	187,81	498,00	371,74
2011 Winter	3,59	245,78	382,64	260,59
2011 Summer	3,84	265,91	125,22	502,33
2012 Winter	4,37	210,00	99,62	282,40
2012 Summer	1,26	416,95	152,18	254,73
2013 Winter	2,26	314,01	429,71	737,46
2013 Summer	0,55	425,10	172,39	655,31

NO_2-N concentration: The earliest observed NO_2-N concentrations where the mean concentration between 2010 and 2011 was 2.86 μgL^{-1} (Table. 11) and the concentration had increased by the mid-2011's to 3.839 μgL^{-1}; this was followed by a slight, but statistically significant, decrease to 0.548 μgL^{-1} by 2012–2013 in the Sea of Marmara (Figure 2).

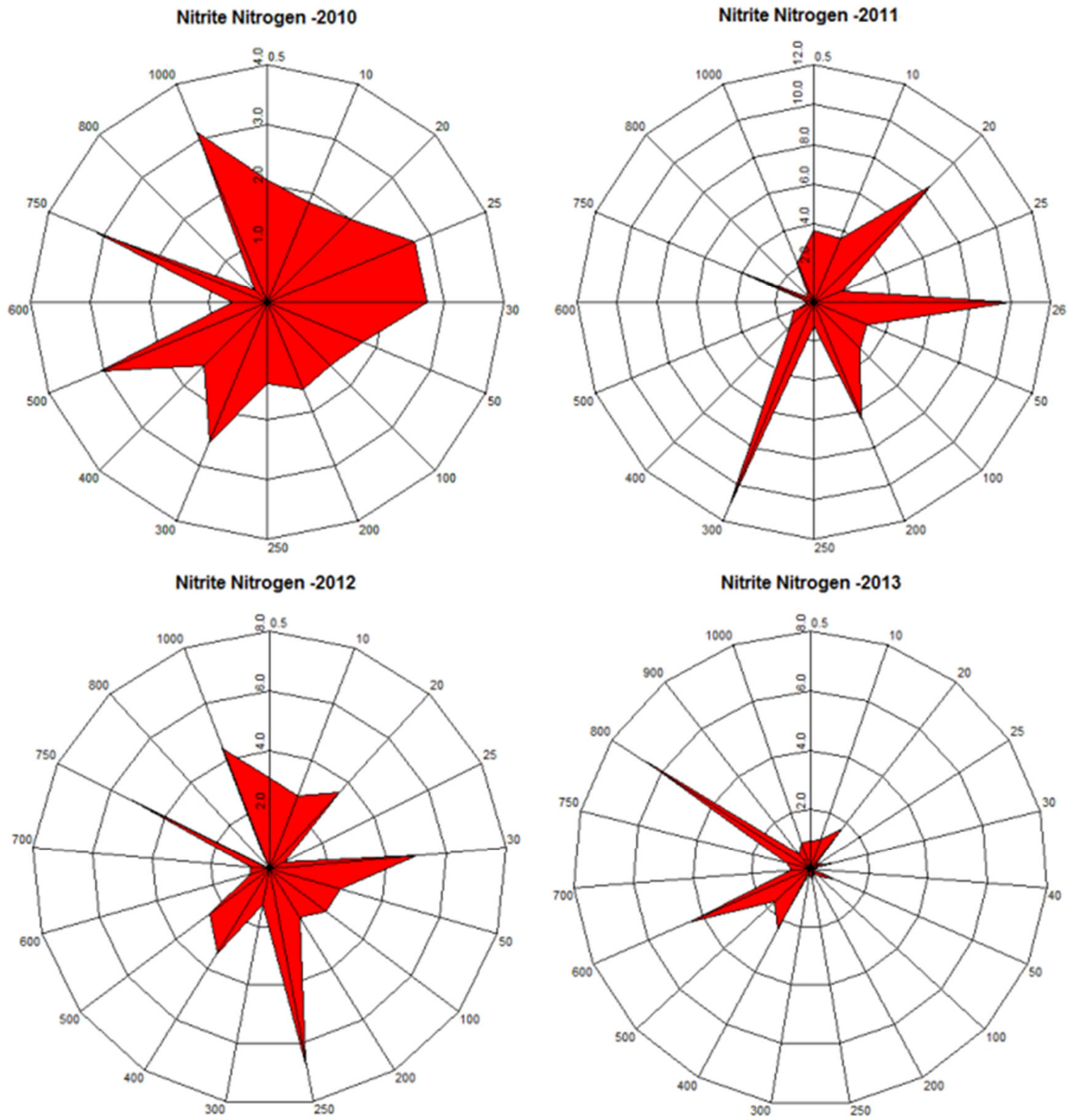


Figure 2. Average long-term nitrite nitrogen distribution/fluctuation of whole Sea of Marmara area incl. Turkish Straits, in depth basis between years 2010 and 2013.

The mean ratio fluctuates between a maximum value of 4.51 μgL^{-1} in the Mediterranean Sea originated lower layer, with the other words under the pycnocline, with a mean salinity of 38‰, in 900 m depth and with a minimum value of 0.57 μgL^{-1} in upper, Black Sea originated water mass, in depth of 26 m, in a converse manner, between years 2010 and 2013 (Table. 12).

Mean NO_2-N (μgL^{-1}) value fluctuations against salinity (‰Sal) between 2010 and 2013 are given in Figure. 3.

NO_3-N concentration: The development of the NO_3-N concentration in the Sea of Marmara between 2010 and 2013 is quite uniform with a minimum mean concentration of 213.12 μgL^{-1}, and with a maximum mean concentration of 502.5 μgL^{-1} in the Black Sea originated water.

(Figure 4). The deeper sections below 50 m, in other words; the layer under the halocline, have a semi-constant mean value in a range of 179.37 μgL^{-1} and 534.33 μgL^{-1}(Table. 12).

Table 12. Mean nutrient values based on layers (upper and lower) between years of 2010 and 2013.

		2010		**2011**		**2012**		**2013**	
		Winter	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**
NO_2-N (μg.L^{-1})	Upper Layer	2.14	2.09	3.85	4.26	3.95	0.90	1.48	0.46
	Lower Layer	1.99	1.91	3.32	3.69	4.51	1.37	2.73	0.57
NO_3-N (μg.L^{-1})	Upper Layer	502.5	213.12	241.78	237.81	221.03	333.16	335.82	353.36
	Lower Layer	534.33	179.37	249.78	275.27	206.31	442.73	307.29	445.59
PO_4-P (μg.L^{-1})	Upper Layer	516.83	504	381.94	119.40	98.11	163.42	473.60	210.09
	Lower Layer	516.5	486	383.33	127.15	100.12	150.10	416.2	161.61
NH_4-N (μg.L^{-1})	Upper Layer	378.89	298.62	261.5	348.04	243.23	220.52	396.18	804.32
	Lower Layer	322.22	396.12	259.67	553.75	295.45	265.26	438.67	494.79

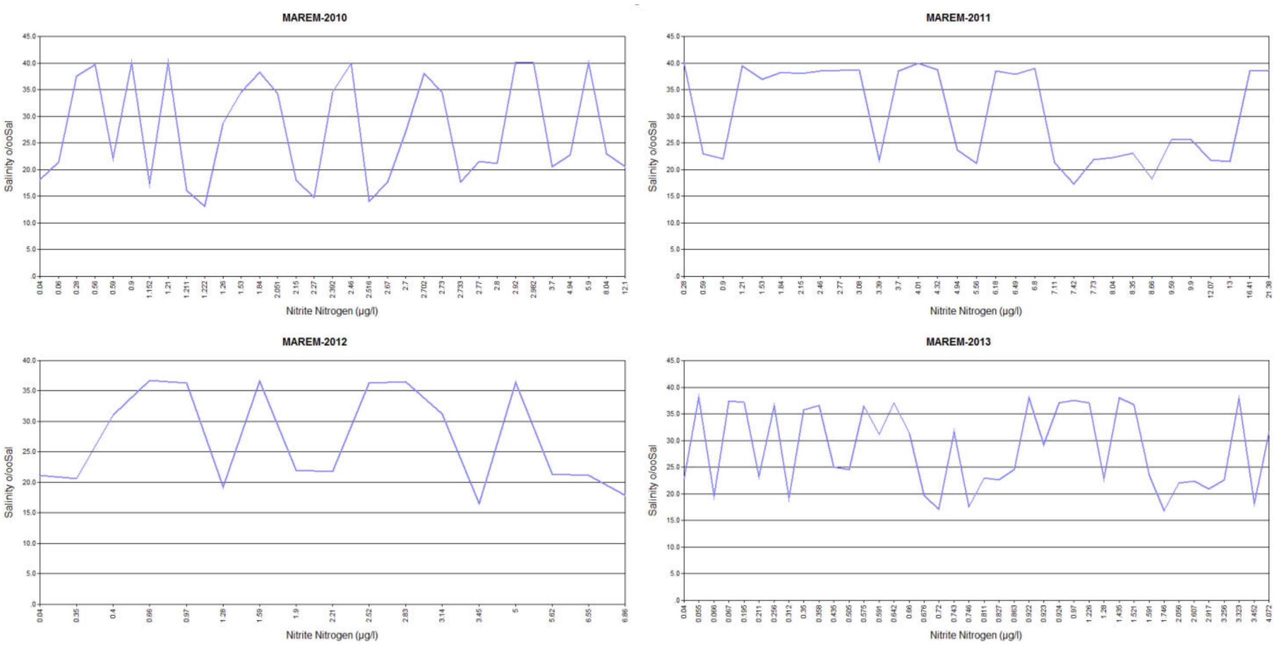
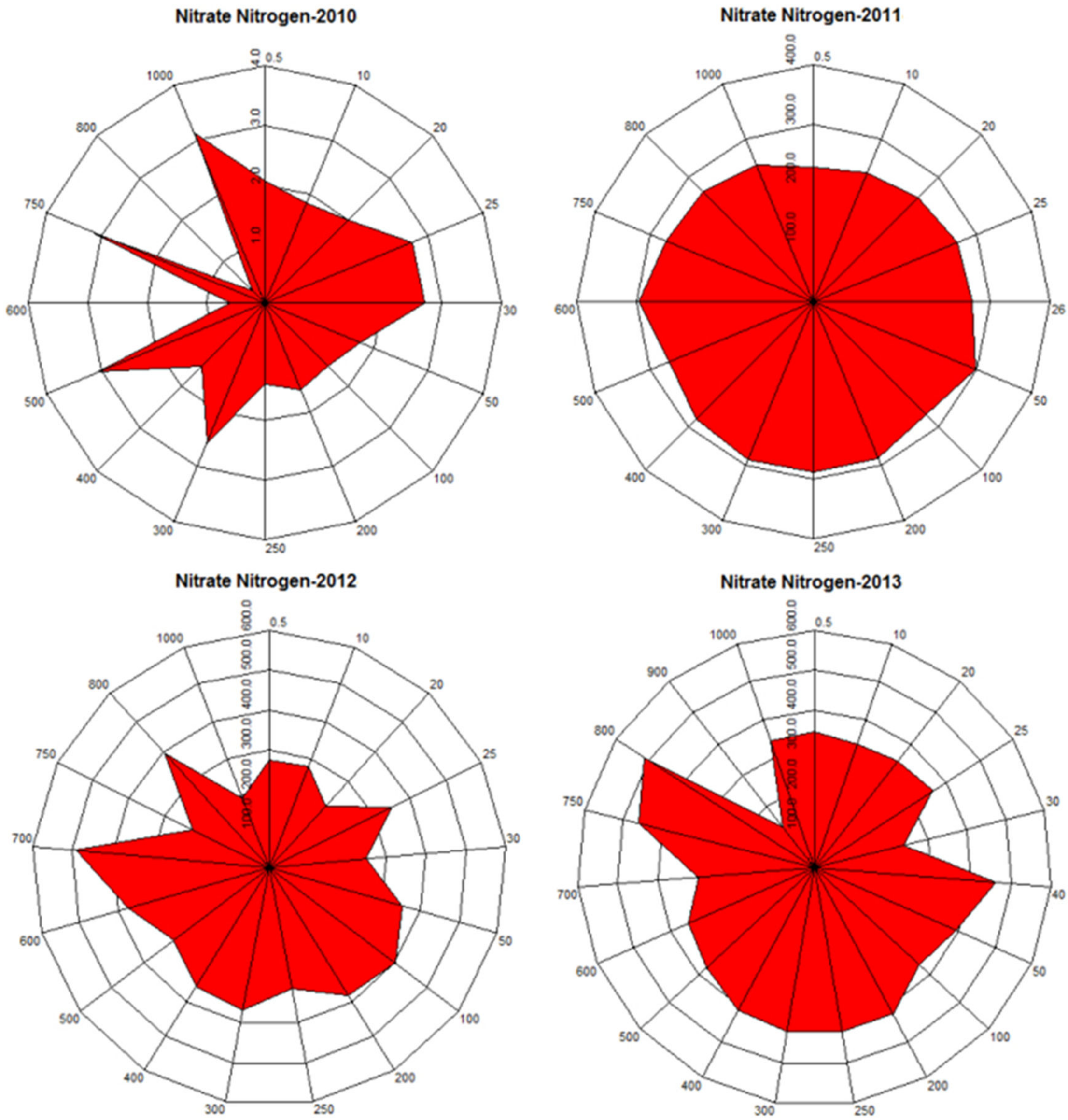


Figure 3. Average long-term nitrite nitrogen - salinity distribution/fluctuation of whole Sea of Marmara area incl. Turkish Straits, in depth basis between years 2010 and 2013.


Nitrate Nitrogen-2010
0.5
10
20
25
30
50
100
200
250
300
400
500
600
750
800
1000
1.0
2.0
3.0
4.0
Nitrate Nitrogen-2011
0.5
10
20
25
26
50
100
200
250
300
400
500
600
750
800
1000
100.0
200.0
300.0
400.0
Nitrate Nitrogen-2012
0.5
10
20
25
30
50
100
200
250
300
400
500
600
700
750
800
1000
100.0
200.0
300.0
400.0
500.0
600.0
Nitrate Nitrogen-2013
0.5
10
20
25
30
40
50
100
200
250
300
400
500
600
700
750
800
900
1000
100.0
200.0
300.0
400.0
500.0
600.0

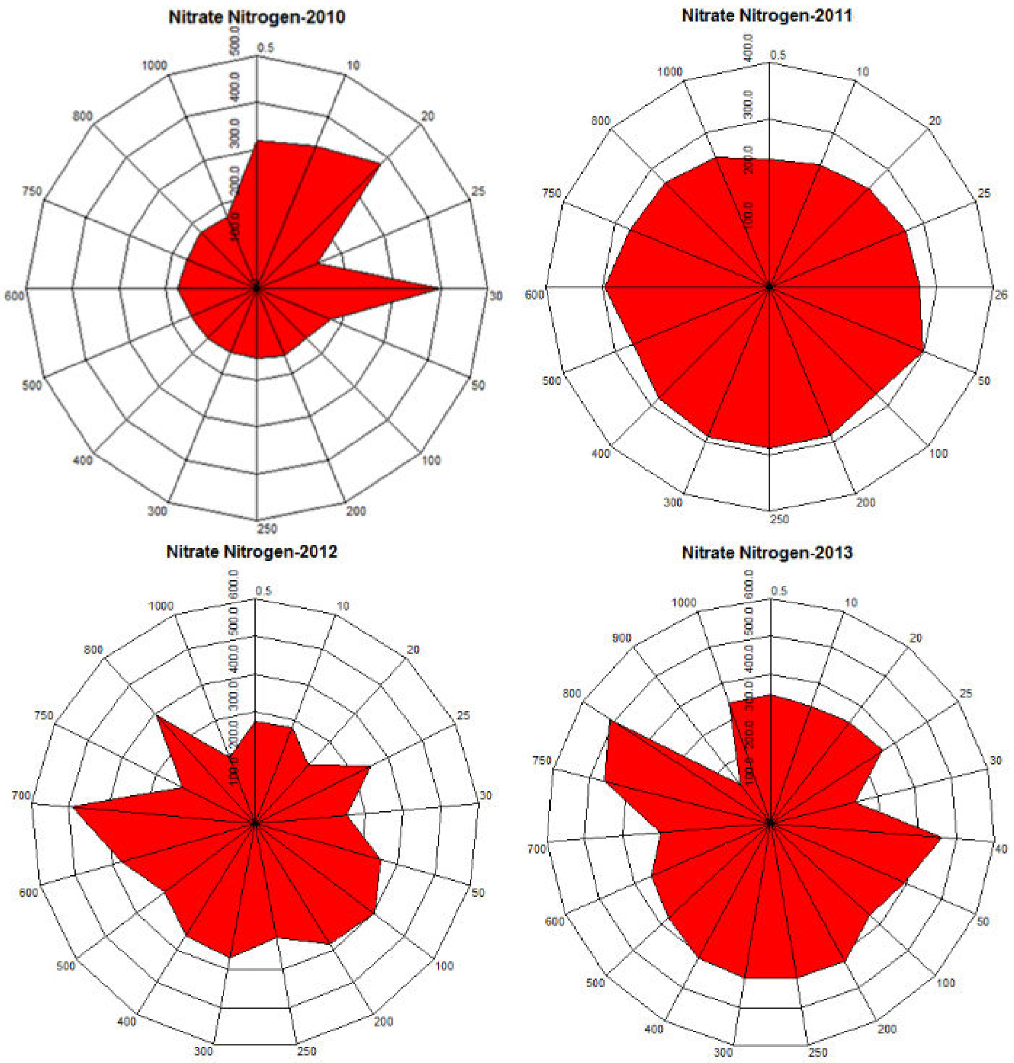


Figure 4. Average long-term nitrate nitrogen distribution/fluctuation of the whole Sea of Marmara area incl. Turkish Straits, in depth basis between years 2010 and 2013.

Regarding the measurements in the period of 2010 and 2013, a regular time-dependent change of the development of the NO_3-N concentration in either layer can be mentioned.
Mean NO_3-N (μgL^{-1}) value fluctuations against Salinity (‰Sal) between 2010 and 2013 are given in Figure 5.

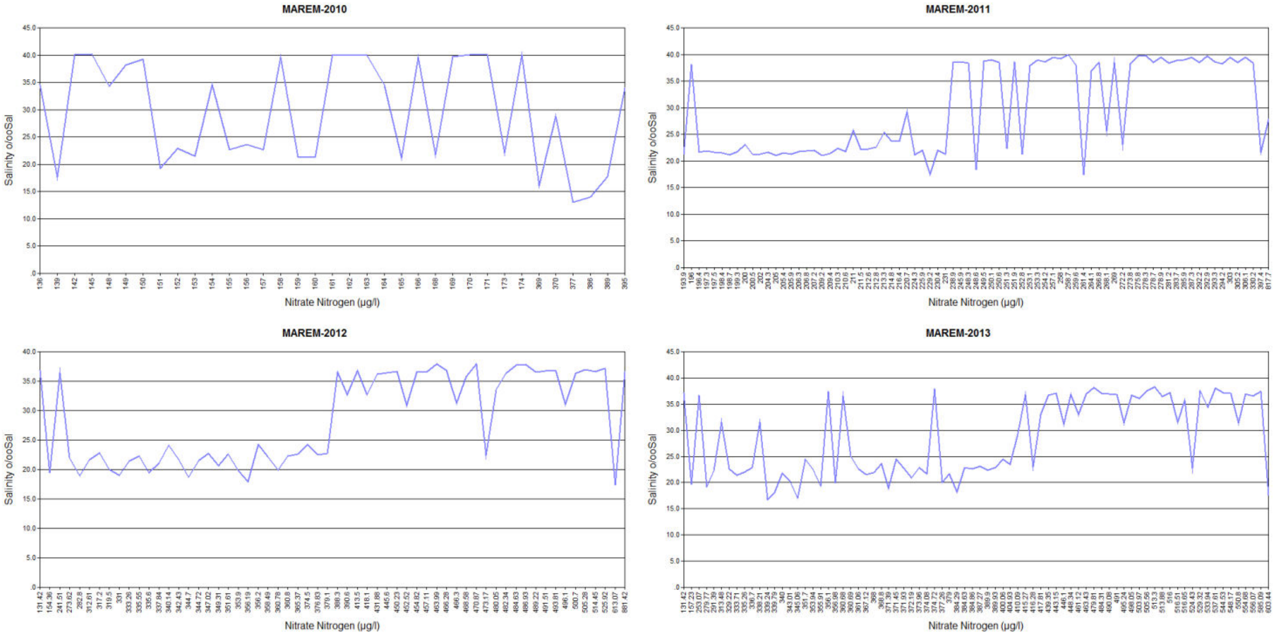


Figure 5. Average long-term nitrate nitrogen - salinity distribution/fluctuation of whole Sea of Marmara area incl. Turkish Straits, in depth basis between years 2010 and 2013.

NH_4-N concentration: Throughout the study period, the mean concentration of NH_4-N between 2010 and 2011 was 371.30 µgL^{-1}, increasing to 482.47 µgL^{-1} in the 2012–2013 period as an average value for the whole Sea of Marmara (Table. 11) (Figure 6).

The mean ratio fluctuates between a maximum value of 553.75 µgL^{-1} in the Mediterranean Sea originated lower layer, with the other words under the pycnocline, with a mean salinity of 38‰, in 900 m depth and with a minimum value of 259.67 µgL^{-1} in upper, Black Sea originated water mass, in depth of 26 m, in a converse manner (Figure 6) (Table. 12).

Mean NH_4-N (µgL^{-1}) value fluctuations against Salinity (‰Sal) between 2010 and 2013 are given in Figure 7.

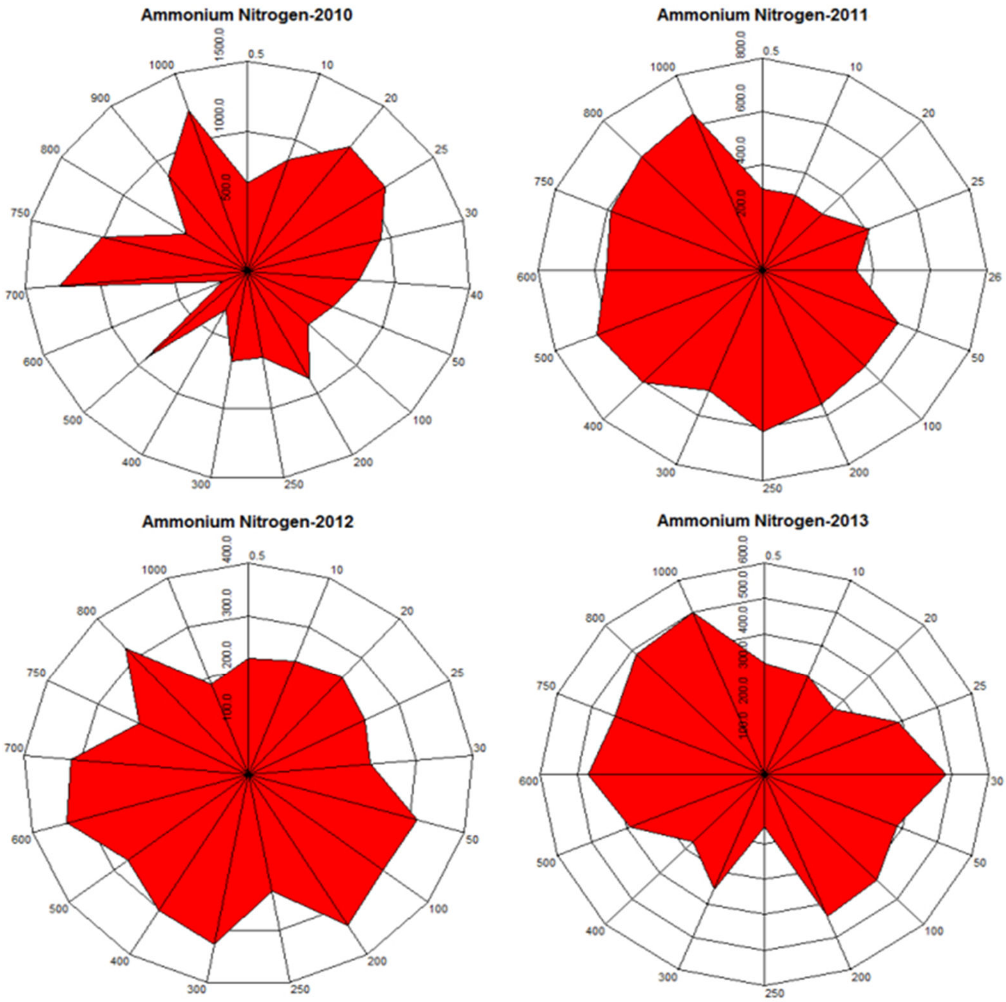


Figure 6. Average long-term ammonia nitrogen distribution/fluctuation of the whole Sea of Marmara area incl. Turkish Straits, in depth basis between years 2010 and 2013.

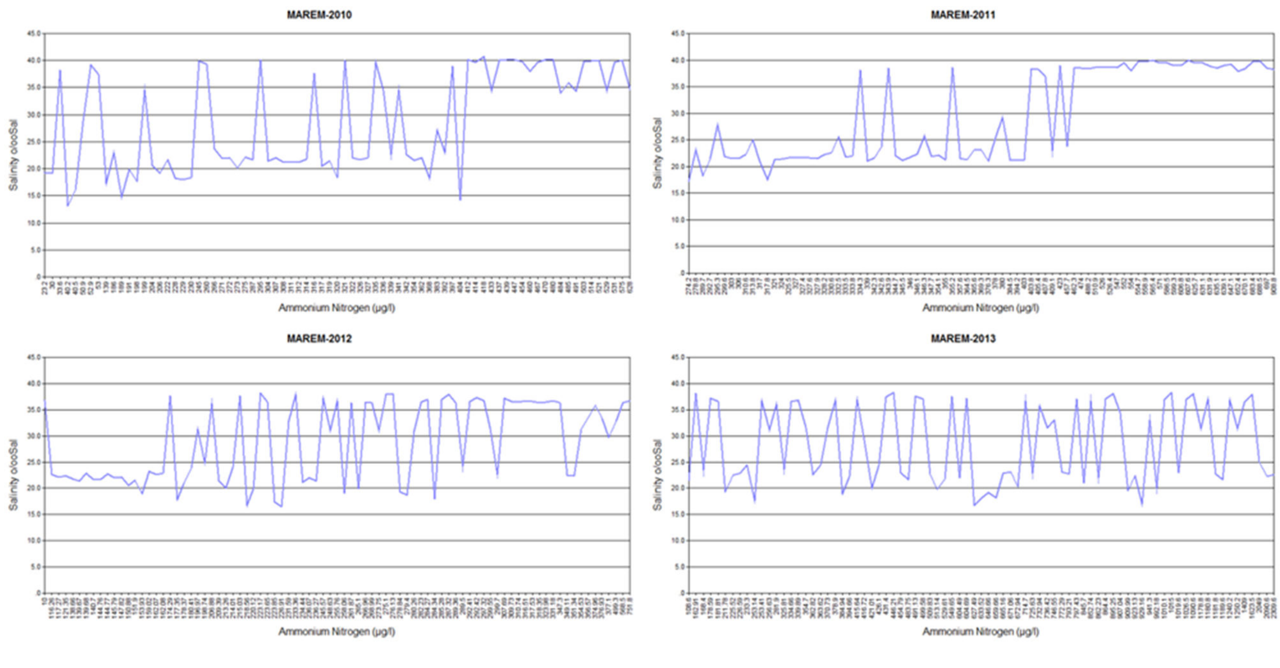


Figure 7. Average long-term ammonia nitrogen - salinity distribution/fluctuation of whole Sea of Marmara area incl. Turkish Straits, in depth basis between years 2010 and 2013.

Also, the upper layer comprises a mean maximum of 804.327 μgL^{-1} and a mean minimum of 220.52 μgL^{-1}, whereas the lower layer with a mean maximum of 553.755μgL^{-1} and a mean minimum of 259.67 μgL^{-1} (Table. 12)

PO_4-P concentration: The PO_4-P ratio shows an extraordinary dispersion in the Sea of Marmara with all sub-regions including bays and straits and water masses. The PO_4-P mean ratio is remained with minimum 98.11 μgL^{-1}, winter 2012, and with a maximum 516.83 μgL^{-1}, in winter 2010, in the Black Sea originated upper layer with average salinity of 28‰; whereas with minimum 100.12 μgL^{-1} in winter 2012, and with a maximum 516.50 μgL^{-1}, in winter 2010, below the pycnocline in the Mediterranean originated water mass with a mean salinity of 38‰ throughout the study period (Figure 8) (Table. 12).

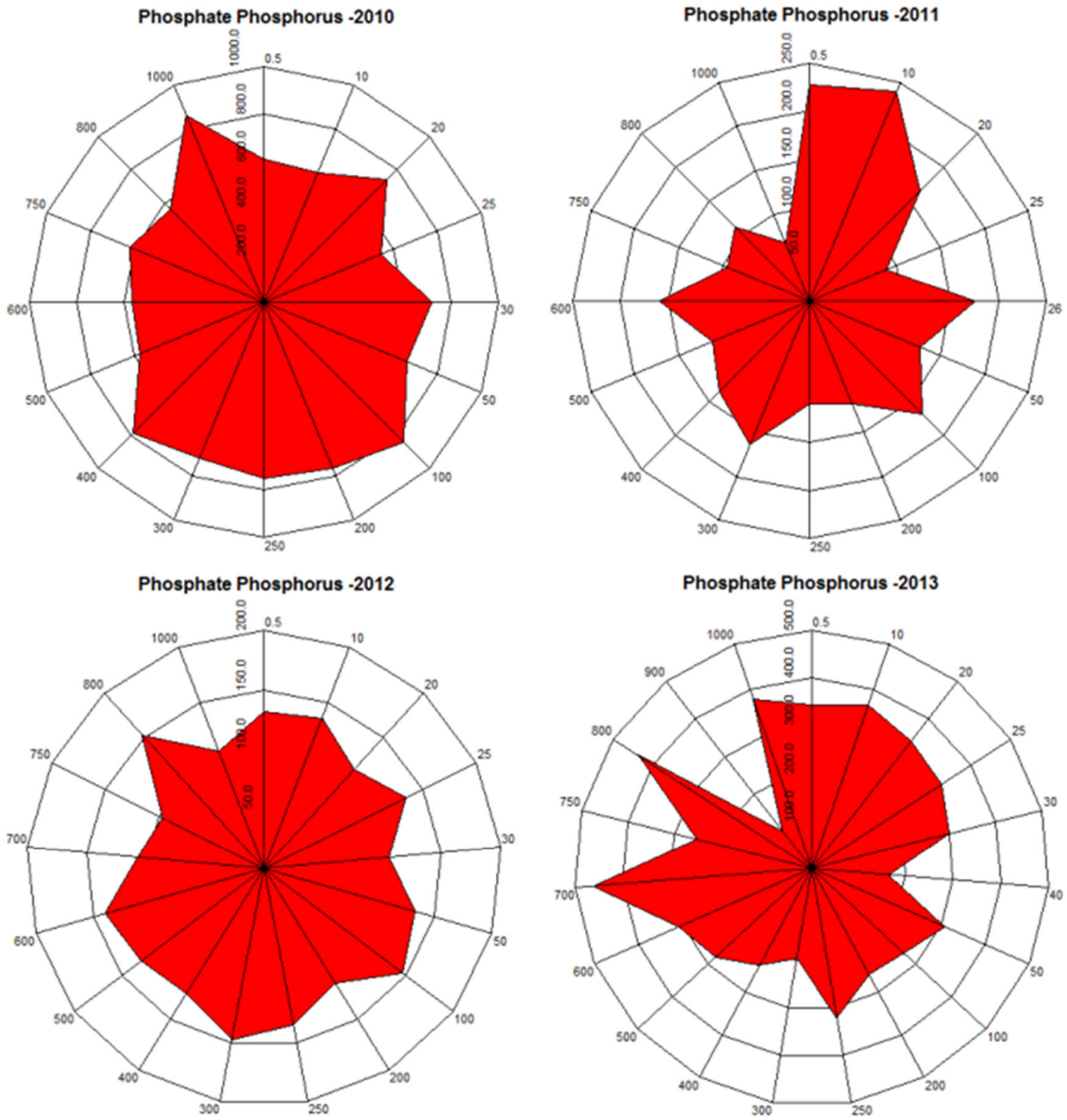


Figure 8. Average long-term phosphate phosphorus distribution/fluctuation of the whole Sea of Marmara area incl. Turkish Straits, in depth basis between years 2010 and 2013.

Mean PO_4-P (μgL^{-1}) value fluctuations against Salinity (‰Sal) between 2010 and 2013 are given in Figure 9.

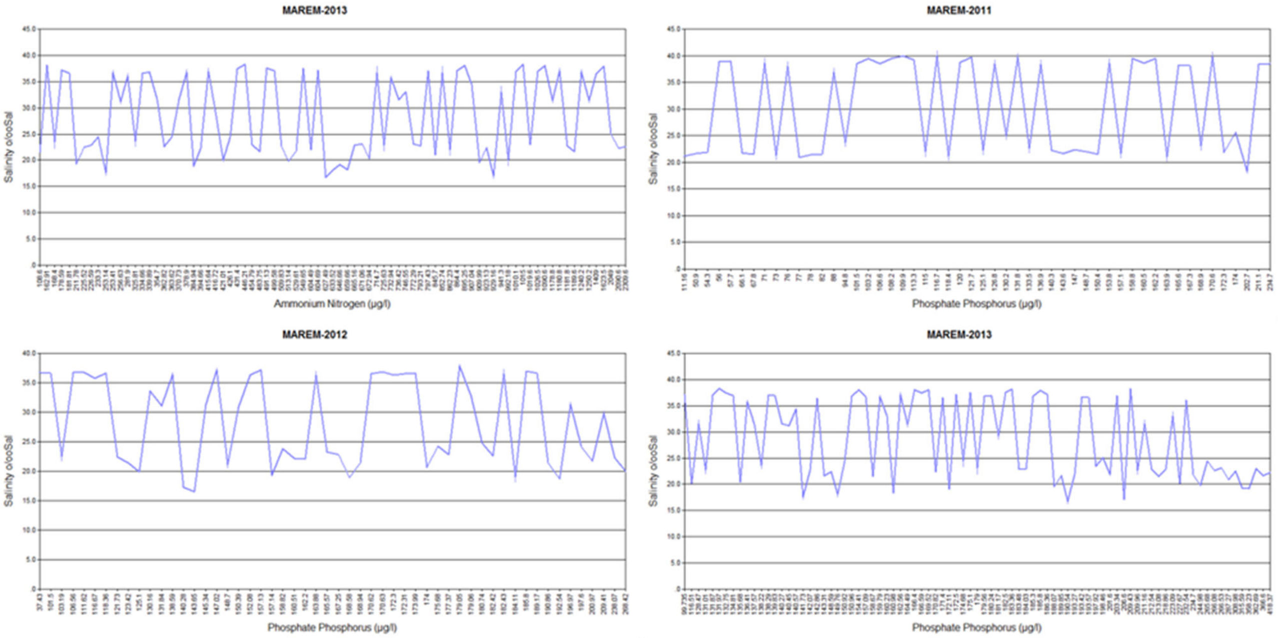


Figure 9. Average long-term phosphate phosphorus- salinity distribution/fluctuation of whole Sea of Marmara area incl. Turkish Straits, in depth basis between years 2010 and 2013.

DISCUSSION

The Sea of Marmara has unique hydrodynamic features, which connect it to the Mediterranean Sea via Dardanelles and to the Black Sea via Bosphorus.

The Sea of Marmara receives heavy inputs of municipal and industrial wastewater from Istanbul and adjacent populated areas around the region. Significant industrial wastewater and more amount of municipal wastewater still enter unthreatened. Especially critical areas, which receive wastes from Turkey’s major industrial centres, are in need of stronger pollution control measures including İzmit and Gemlik Bays.

The major pollution source here and in the Straits are the release of wastewaters without any treatment via “deep sea discharges” with the principal to use the below water mass, that flows from the Aegean Sea to the Black Sea, as a conveyor. However, the whole Sea of Marmara behaves as a semi-enclosed system, retaining most of the substances arriving there. It is caused by three factors: the morphology of the straits, bi-directional current event, and the dominating wind regime **(3)**.

Water quality and biodiversity along Sea of Marmara coastline is under heavy pressure from extensive domestic and industrial wastewater inflow, and from intensifying the development of uniquely and fragile areas for maritime transport based landing facilities and power plants.

On the other hand, especially in narrow and shallow thresholds such as Turkish straits with several points with strong divergence and convergence mixture points, that raids the density differences and enables mixture **(3)**.

It should be noted that almost all sea currents flow in circular direction because of the Coriolis force effect. However, the outflow from the Black Sea basin is a function of its water budget and carry runoff from the large rivers and surface waters run into the Black Sea and forces the flux to the north-west direction, and on the contrary, the below flux is a function of density of Mediterranean-originated heavy saline water that flows to the opposite direction. They are both directional fluxes.

The DO content of the deeper waters (under the pycnocline layer) of the Sea of Marmara is dramatically low. This is most probably due to the increased pollution caused by the discharge of the sewages under the pycnocline layer without any treatment and by the great difference in density between the surface layer and the deeper waters, which impedes convection.

The concentrations of the nutrients (phosphate, nitrate, nitrite, ammonium, *etc*.) are the main limiting factors for the primary productivity. Concentration and depth (*i.e.,* origin of the water mass) during mid and late winter, when the phytoplankton standing stocks are their lowest levels nutrients reach high values trough out the winter water column. The highest phosphate and nitrate in the waters of the area is also attributed to the runoff from Black Sea Rivers which occupies the surface layers.

Very large changes take place as the surface waters are warmed and by the growth of plant life and phytoplankton blooms in spring. The nutrient concentrations decrease rapidly during the summer months, where concentrations of nutrients at the surface layers fall to very low values, but the levels below the thermocline are maintained or may be somewhat increased.

A calculation of primary productivity from the concentrations of nutrients in the seawater cannot be applied to the whole working area, due to horizontal irregularities in the distribution of these values. (As shown in Figures 2-8 of the present paper) Another obstacle for such a calculation will be the anthropogenic impact on the marine environment regarding the concentrations of the nutrients. This impact can be clearly traced southwards of the Sea of Marmara, including the impact area of mega city Istanbul. The effect is prominent in the south of Bosphorus and in the Izmit Bay where the nutrients are in excess of that required by marine life, causing heavy eutrophication in this water. Because of heavy sewage load to the strait a rapid increase in nutrient content has been observed in the waters of Sea of Marmara.

Changes in the concentration of PO_4 in the different layers of the Sea of Marmara are striking. As will be clearly seen the average concentration of PO_4 has about four times increased in between 2012 winter and 2013 winter period (Table. 10). Changes which is about 12 times at phosphate concentration is not only at different layers but also at the same water masses and same period with a value of 142.070 $\mu g.L^{-1}$ at the 2013 summer study and 11.160 $\mu g.L^{-1}$ at 2011 summer study(station 40 surface water) Table 8.

Therefore, nutrient surveys in the waters of the Sea of Marmara should take the anthropogenic nutrient load into consideration to explain the anomalies in nutrient distribution. As it has been suggested by several authors for similar conditions, the dissolved oxygen content of the water column may be used for calculation of the primary production. For the primary productivity, vertical mixing of the water layers of the Sea of Marmara is more important than the strength of the of the Black Sea current to the straits limiting the distribution of nutrients and as well as the distribution of the dissolved oxygen content.

Same trends may be observed in the nitrogen concentrations in the area. The periodical increases of the NO_3 may be an explanation for the progressively and dense red-tide in the Sea of Marmara.

Except red-tide concentrations of *Noctiluca scintillans* (Macartney) Kofoid & Swezy, 1921 at the surface, the highest accumulations of planktonic organisms are found at the pycnocline (on whole isopycnal zone), which may be observed on echograms **(5)**.

The unaffected mass of water, which occupies all depths below 200 m in the Sea of Marmara, has a constant average temperature of 14.2°C, without any seasonal variations **(3-5, 12)**.

CONCLUSIONS

Excess nutrient inputs lead to eutrophication and degradation of the aquatic system. Depending on the distribution of the nutrient salt concentrations, clear signs of eutrophication can be seen in the Sea of Marmara proper.

In general -although with some exceptions due to biochemical processes- nutrients have a conservative relationship with salinity, so their concentrations are lower when salinity levels are higher.

Regarding to the complex, two-layer system of the Sea of Marmara, the concentration of nutrients in the both layers fluctuates simultaneously with a decrease in oxygen concentrations and increases in the salinity, depending on the distance to the origin of the water masses such as low salinity/density of Black Sea water and high salinity/density Mediterranean water.

In the previous studies, the low salinity water that flows from the Black Sea were presented as the reason for a possible load of the additional nutrient amount to the Sea of Marmara via Bosphorus. This led to different and wrong interpretations.

However, the real reason of fluctuating distribution ranges of nutrients in different parts of the Sea of Marmara waters is the underlying cause of the unique hydrographical conditions of the Sea of Marmara.

As lower-salinity waters remain confined in the upper part of the water column, the higher nutrient concentrations are generally located in the surface layers. Pollutants follow a similar pattern. As in the case of the Sea of Marmara, discharges without any treatment to the below and dense water mass are affecting the whole water column of different degrees, regarding the density equivalency.

Also the 3 basins with more than 1000 m depth with the position each one of the other, located in a course under main and both direction water masses, acts as a sink for waterborne particles (Sediments, nutrients and pollutants), most of which remain trapped there.

This picture indicates that a considerable accumulation of trapped dangerous particles, must be taking place in the Sea of Marmara sediments.

As previously mentioned as biological view **(3)** it clearly appears as a result of the steady erosion of biodiversity of the Sea of Marmara, in last two decades.

ACKNOWLEDGMENTS

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Türkçe Öz ve Anahtar Kelimeler

Nutrition Profile of the Sea of Marmara Between Years 2010 and 2013

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Öz: Marmara Denizi'nde beslenme yükünü tayin etmek için, 25 istasyonda örneklemeler yapılmış ve yüzeyin standart dikey bölgelerinden istasyonun en derin noktasına kadar örnek alınmıştır. Örneklemeler 2010 ve 2013 yılları arasında yılda iki kere yapılmıştır. Nitrat azotu, nitrit azotu, amonyum azotu ve fosfat fosforu süzülmemiş su örneklerinde analiz edilmiştir; buna ilave olarak, tuzluluk, sıcaklık, çözünmüş oksijen ve pH gibi önemli roller oynayan bazı fizikokimyasal parametreler de her istasyonda ölçülmüştür.Bu çalışma Marmara Denizi'ndeki besleme yükünü, bu besleyicilerin durumu üzerine öncül değerlendirme olarak bildirmekte ve Marmara Denizi'nin benzersiz oşinografik durumu hakkında kısa bir tartışma sunmaktadır.

Anahtar kelimeler: Marmara Denizi; besleyici; piknoklin; termoklin; haloklin; kirlilik.

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