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Nutrient dynamics and eutrophication in the Sea of Marmara: Data from recent oceanographic research

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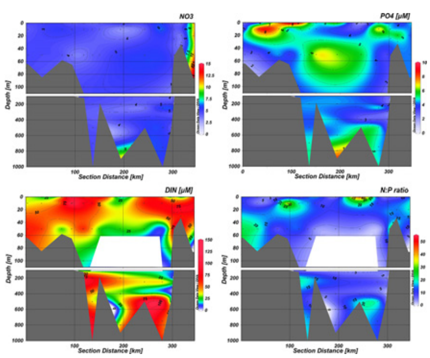
HIGHLIGHTS

- Recent physicochemical and biological data in the Sea of Marmara and the TSS
- Classification of the surface waters into Moderate to Bad trophic status
- Estimation of the seasonal nutrient fluxes exchanged through the TSS

GRAPHICAL ABSTRACT



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ABSTRACT

This work was implemented to study the physicochemical and biological characteristics of the Sea of Marmara and the Turkish straits (TSS: Bosporus and Dardanelles straits) for the period 2010–2013 and to calculate winter and summer fluxes of nutrients (nitrates, phosphates) between the Aegean and Black Seas through the TSS. The brackish Black Sea waters reach the Dardanelles Strait with modified biochemical properties. The salinity and phosphates of the surface waters increased westwards. Biologically labile nutrients of Black Sea origin are utilized through biological processes in the Marmara Sea. On the other hand, increase of nutrients due to land based sources has led to eutrophication problems in the area. The sub surface water layer of Mediterranean origin is oxygen depleted (saturation < 30%) and rich in nutrients. Higher oxygen values indicated water mixing of the Sea of Marmara during winter 2012. Ammonium was the predominant form of inorganic nitrogen. The study area has been classified from Moderate to Bad trophic status. İzmit Bay also faced serious eutrophication problems together with hypoxic conditions below the halocline. Nutrient fluxes through the TSS showed temporal variation in the upper and lower layers related to changes in both nutrient concentrations and the water mass volume fluxes. Surface nitrates and phosphates outflux from the Sea of Marmara to the Aegean Sea was higher than the influx from the Black Sea through Bosporus strait, indicating high enrichment of nutrients in the Sea of Marmara from anthropogenic sources.

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1. Introduction

The Sea of Marmara is about 210 km long and 75 km wide (11,500 km^2), with 927 km of coastline and connections to the Black Sea at its eastern side and the Mediterranean Sea (Aegean Sea) at its western side. Regarding the maximum depth of the Sea of Marmara, the most accurate data has been obtained by the French Research Institute for Exploitation of the Sea, IFREMER (Rangin et al., 2001), indicating a maximum depth of 1273 m. Its hydrography is essentially determined by the water exchanges through the straits (e.g., Jarosz et al., 2013; Aloisi et al., 2015; Mavropoulou et al., 2016; Goldberg et al., 2016; Kokkos and Sylaios, 2016; Ozturk et al., 2017). Low salinity (S ~ 17–18 practical salinity units, PSU) Black Sea water (BSW) enters the Sea of Marmara through the Bosporus Strait, occupying its surface layer, whereas salty (S ~ 39 PSU) waters from the oligotrophic East Mediterranean Sea (Aegean Sea) enter the deeper layer of the Sea of Marmara through the Dardanelles Strait (Ullyott and Ilgaz, 1946; Ullyott and Pektaş, 1952; Türkoğlu et al., 2006). It is noteworthy that the annual volume influx from the Black Sea to the Sea of Marmara through the Bosporus Strait is nearly twice the salty water outflux from the Marmara to the Black Sea (e.g. Ünlüata et al., 1990a, 1990b; Beşiktepe et al., 1994; Tuğrul et al., 2002). The salinity of the inflowing BSW increases slowly along its pathway into the Sea of Marmara and reaches values of ~30 PSU at the exit of the Dardanelles Strait to the Aegean Sea. On the other hand, at the same time, the salinity of the inflowing Aegean waters decreases slowly to 29 PSU along the pathway of the Aegean waters within the deeper layer of the Sea of Marmara (Artüz et al., 2008). The outflowing and inflowing water masses are separated by a well-defined layer of transition, which oscillates up and down following the bathymetry. This transition layer also represents a discontinuity layer with respect to temperature and salinity and is called the thermohalocline (Artüz et al., 2009; Artüz et al., 2010a, 2010b, 2010c). As a result, there is a strong salinity-driven density gradient and a halocline that limits the vertical supply from the deeper layers.

The Sea of Marmara is a region of particular importance since the strong density gradient layer between water masses may have a significant influence on mixing processes, nutrients, and dissolved oxygen dynamics (Uyguner, 1957; Beşiktepe et al., 1994; Tuğrul et al., 2002; Kara et al., 2009; Altıok et al., 2014; Ozturk et al., 2017). Indeed, the difference in density between the Mediterranean and the BSWs has resulted in a two-layer current system flowing in opposite directions along the Sea of Marmara and the Turkish Straits. Intensive mixing takes place along the Bosporus as well as in the other parts of the straits.

The chemical oceanography of the Sea of Marmara is significantly influenced by the biochemistry of the Black Sea and the Aegean Sea. In the euphotic zone, the concentrations of nutrients are relatively low and show seasonal fluctuations that reflect the photosynthetic activity, whereas the sub-halocline waters of Mediterranean origin are rich in nutrients (Polat et al., 1998; Balkis, 2003a). The BSWs carry the runoffs from the large rivers discharging into the Black Sea. It is known that relatively high amounts of nutrients discharge into the surface layer of the Black Sea, leading to the development of eutrophication phenomena (Tuğrul et al., 2014). As a result, the BSW probably affects the nutrient distribution of the surface layer of the Sea of Marmara. Besides that, exponentially growing pollution has been a serious problem in the Sea of Marmara since 1980. The coastal areas of the Sea of Marmara pollute the marine environment of Marmara with untreated sewage discharging below the pycnocline (Artüz et al., 2007). Istanbul is one of the most highly populated cities in the world and faces unplanned and uncontrolled urbanization. In the 1980s, Istanbul used water from the Mediterranean Sea to transport wastewater and discarded this into the Black Sea. According to Arslan-Alaton et al. (2009), there are >15 mostly primary wastewater treatment plants located at the Bosporus Strait and along the coastline of the Sea of Marmara, which affect the water quality and the trophic status of the area. Thus, the Sea of Marmara is under pressure from dramatic pollution from high anthropogenic activities, industrialization, and agricultural activity, together with pollutants originating from the Black Sea that are carried via the Bosporus (Balci and Balkis, 2017 and references therein).

Considering the importance of the area, there are few published studies dealing with the nutrient distribution in the Sea of Marmara (e.g., Uyguner, 1957; Baykut et al., 1987; Ergin et al., 1993; Polat and Tuğrul, 1995; Tuğrul and Polat, 1995; Polat et al., 1998; Tuğrul et al., 2002; Zeri et al., 2014) and the seasonal variability of phytoplankton in this region (e.g., Aubert et al., 1990; Uysal, 1987, 1996; Öktem, 1997; Balkis, 2000; Balkis, 2003b; Aktan et al., 2005; Balci and Balkis, 2017). Thus, very few publications have provided new information during the last few years even though, during the last four decades, drastic changes related to anthropogenic pressures have occurred in the Sea of Marmara ecosystem. Moreover, there are very few studies covering the whole area of the Sea of Marmara and the Turkish Straits.

Therefore, this work attempts to fill these gaps by providing new information about dissolved oxygen, nutrients, and phytoplankton biomass patterns in the Sea of Marmara, İzmit Bay, and the Dardanelles and Bosporus Straits. This may also have essential significance with respect to environmental management. The seasonal and spatial variations are studied in relation to the hydrographic regimes and the anthropogenic pressures in the study areas. The nitrogen to phosphorus (N:P) ratio is also discussed. Finally, an effort has been made to estimate the nutrient fluxes exchanged between the Aegean Sea and the Sea of Marmara via the Dardanelles Strait and between the Black Sea and the Sea of Marmara via the Bosporus Strait.

Data from the MAREM project has been used in this work. Marine monitoring using classical ship-based surveys is considered to be costly in time and money and whether depended; thus, in many cases, the sampling rate is typically insufficiently low and discontinuous. The Marmara Environmental Monitoring (MAREM) project is one of the longest standing surveillance projects concerning the Sea of Marmara (1954–today), monitoring the physicochemical and biological characteristics of the Sea of Marmara and the Turkish Straits and studying their changes over time. The importance of this project and this work is that it provides new information to advance our knowledge of physicochemical and biological characteristics and covers a broad geographical area: the whole area of the Sea of Marmara and the Turkish Straits. This work is based on data for the period 2010–2013. Data from 2014 to today will be assessed and used in future work.

This paper is organized as follows: Section 3.1 describes the hydrological characteristics (Temperature-T, Salinity-S) of the Dardanelles Strait, the Sea of Marmara, and the Bosporus Strait, presented as vertical distributions along a transect from the Dardanelles Strait to the Bosporus Strait. The hydrological regime is discussed. Section 3.2 describes the biochemical characteristics (dissolved oxygen (DO), nutrient and phytoplankton biomass distributions, and nutrient ratios) of the Sea of Marmara and the Dardanelles and Bosporus Straits. Section 3.3 provides information on the eutrophication status of the study area. The İzmit Bay area is discussed separately in Section 3.4. In Section 3.5, the nutrient fluxes are estimated based on water fluxes estimated in previous studies (Mavropoulou et al., 2016 and references therein; Tuğrul et al., 2002).

2. Materials and methods

This work was contracted within the framework of the MAREM Project. It is based on data obtained during eight survey cruises in the Sea of Marmara in winter and summer during the period 2010–2013, using a large fishing vessel named OKTAY–4, which is especially designed for oceanographic studies. Physicochemical and biological measurements were conducted at 23 stations in the Dardanelles and Bosporus Straits, in the Sea of Marmara, and in İzmit Bay (Fig. 1, Tables S1, S2). Seawater samples were collected with Niskin bottles with a volume of 2.5 L designed by the MAREM project leader. The samples were directly filtered during sampling