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# Transparent Exopolymer Particles (TEP) in the NE Aegean Sea frontal area: Seasonal dynamics under the influence of Black Sea water

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ABSTRACT

The abundance of Transparent Exopolymer Particles (TEP) was determined on a seasonal basis (autumn, spring and summer) along a north-south transect in the NE Aegean Sea and the vicinity of the Dardanelles Straits. Their distribution patterns were studied in respect to hydrographic conditions and water mass characteristics in the area, as well as particulate organic carbon (POC) concentrations, changes in standing stocks of chlorophyll-$\alpha$ and bacterial production. TEP concentrations ranged from 15.4 to 188 μg GX eq $L^{-1}$. Their spatial distribution patterns within the euphotic zone displayed significant seasonal variability, which appears to closely reflect the temporal variation of the water column structure, resulting from the encounter and interplay of the Black Sea and Levantine Water masses, and the associated biogeochemical processes. Minimum TEP concentrations during autumn could be likely attributed to a minor quantity of TEP and/or its dissolved precursors exuded by phytoplankton and their enhanced degradation due to their long residence time in the water column. During spring, high TEP production was mediated by actively growing phytoplankton, while during summer a positive link to the intense stratification of the water column and the enhanced bacterial growth within the Black Sea Water layer was observed. The results reported in this study highlight the fact that TEP carbon represents a significant fraction of the POC pool. Moreover, TEP production is critical in promoting particle coagulation rates, playing an important role in carbon cycling/transportation out of the euphotic zone.

## 1. Introduction

Transparent Exopolymer Particles (TEP) are carbon-rich sticky particles, ubiquitous in both marine and freshwater environments, consisting mainly of acidic polysaccharides. They are determined after staining by the polysaccharide specific dye Alcian Blue (Alldredge et al., 1993; Passow, 2002a).

TEP have been receiving increasing attention over the last years with respect to their importance in carbon cycling in pelagic/oceanic ecosystems (De La Rocha et al., 2008; Engel and Passow, 2001; Engel et al., 2004; Gogou and Repeta, 2010; Mari et al., 2001, 2017; Passow et al., 2001; Wurl et al., 2011). Due to their sticky character, TEP increase the collision rates between particles, mostly in the form of large, rapidly sinking aggregates ( > 0.5 mm in diameter) known as marine snow, thus playing an important role in the export of particulate organic material to the deep ocean and significantly contributing to the coupling between the pelagic and benthic ecosystems (Alldredge and Silver, 1988; Engel et al., 2002, 2004; Passow et al., 2001).

TEP are predominantly formed abiotically by coagulation of colloidal dissolved organic matter, mainly dissolved polysaccharides released from planktonic organisms (Passow, 2002b; Passow and Alldredge, 1994; Waite et al., 1995). TEP are also formed biotically either directly from algal or bacterial extracellular excretion (Hong et al., 1997; Passow, 2002b) or from microbial breakdown of larger marine snow particles (Engel and Passow, 2001) and sloppy feeding by meso- and macro-zooplankton (Passow and Alldredge, 1999). Moreover, bacteria can promote indirectly abiotic TEP formation, acting as nuclei for negatively charged TEP precursors and/or enhancing self-coagulation of precursors due to their pedesis (Passow, 2002b; Stoderegger and Herndl, 1998, 1999). Meanwhile, bacteria also act as consumers of TEP, releasing organic carbon mainly in the dissolved phase (Grossart et al., 2006; Grossart and Simon, 2007; Mari and Kiørboe, 1996; Ortega-Retuerta et al., 2010; Passow, 2002a; Passow and Alldredge, 1994).

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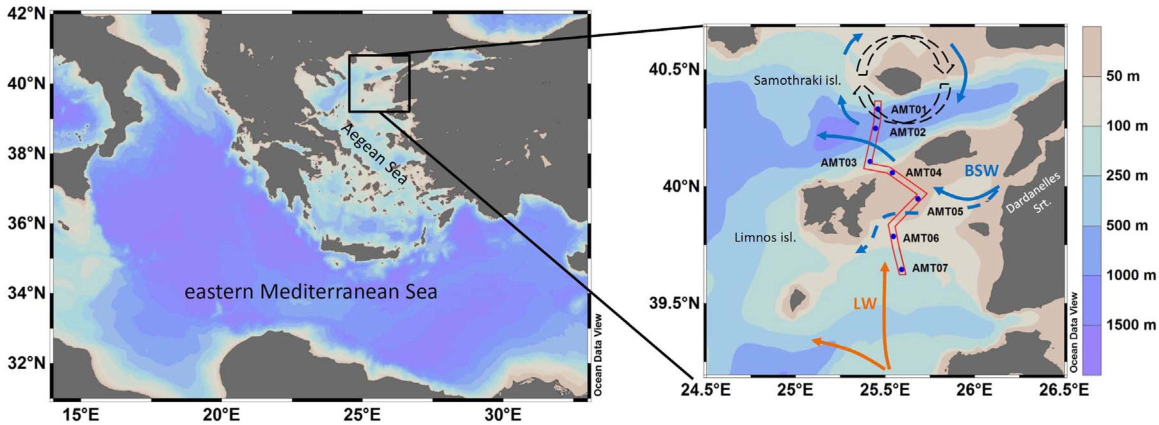


**Fig. 1.** Study area map with the sampled stations along the north-south transect, the main patterns of seawater surface circulation: BSW main pathways during winter (dark blue) and additional pathway during summer (dotted dark blue), LW route towards the north Aegean Sea (orange), and the Samothraki anticyclonic circulation pattern in the northern part of the section. The map was produced using Ocean Data View – ODV (Schlitzer, 2011). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Owing to the above, TEP distribution in marine systems are particularly complex, resulting from a balance between sources, consumption by organisms and sinks (Alldredge et al., 1998; Passow, 2002a). Unfolding the relative importance of the above mechanisms is critical in order to perceive the overall occurrence and dynamics of TEP in the ocean.

The NE Aegean Sea is a highly dynamic marginal sea that connects the Black Sea to the oligotrophic eastern Mediterranean Sea through the Marmara Sea and the Dardanelles Straits. It is characterized by the presence of the rather mesotrophic, less saline Black Sea Water (BSW) mass inflowing from the Dardanelle Straits in the upper water layer, which lie on the top of the saline, dense, oligotrophic Levantine waters (LW) originating in the south Aegean Sea (Velaoras et al., 2013; Zervakis and Georgopoulos, 2002).

The contrasting physical characteristics of these two water masses result in the development of a strong permanent thermohaline front in the area, the position of which depends on the incoming BSW fluxes and the resulting dominant circulation that varies temporally even at short time scales (Zervakis and Georgopoulos, 2002). Following a northwestward path, the inflowing BSW mass is trapped within the Samothraki anticyclone, a permanent hydrographic feature that dominates the eastern part of the Sea of Thrace, flowing around the island of Samothraki, which increases the residence time of the BSW in the area (Androulidakis et al., 2012; Zervakis and Georgopoulos, 2002). During summer, a second branch appears in the BSW route which moves towards the south – southwest direction, as a result of the high outflow of the BSW following the increased river discharges into the Black Sea during spring and the prevailing strong NE winds (Etesians) (Olson et al., 2007; Skliris et al., 2010; Zervakis and Georgopoulos, 2002).

Previous studies in the NE Aegean Sea underline the fact that the inflow of the BSW mass enriched in particulate and dissolved organic matter results in enhanced planktonic biomass and primary production (Ignatiades et al., 2002; Lagaria et al., 2013; Meador et al., 2010; Petihakis et al., 2014; Siokou-Frangou et al., 2002; Souvermezoglou et al., 2014) and an efficient microbial food web (Giannakourou et al., 2014; Pitta and Giannakourou, 2000) in parallel to the progressive intensification of the BSW signal. The contribution of freshwater inputs into the open NE Aegean Sea area is considered rather minor, not exceeding ~20 $km^3\ y^{-1}$, compared to the average flux of the incoming BSW that is estimated to 1160 $km^3\ y^{-1}$ (Jarosz et al., 2013; Poulos et al., 1997). Thus, the impact of riverine loadings variability on the north Aegean ecosystem functioning is constrained in coastal areas (Tsiaras et al., 2014).

Few studies have documented TEP distributions and dynamics in the Mediterranean Sea (Bar-Zeev et al., 2011; Beauvais et al., 2003; Mari et al., 2001; Ortega-Retuerta et al., 2010, 2017; Prieto et al., 2006) and none so ever in the NE Aegean Sea. Based on the determinant role of the presence of the two contrasting water masses in this area on the functioning of the pelagic ecosystem, as described above, it was considered of paramount importance to similarly follow TEP distributions in relation to hydrographic spatiotemporal variability. Therefore here, the spatiotemporal distribution patterns of TEP were investigated for the first time along a north-south transect in the NE Aegean Sea, encompassing spatial gradients between the two dominant water masses, the brackish Black Sea waters and the highly saline waters of Levantine origin. Our goal was to explore the potential controlling factors of TEP distribution patterns, in respect to the unique hydrographic characteristics in the area, and to evaluate their importance for aggregation processes and carbon cycling/ transport out of the euphotic zone.

## 2. Materials and methods

### 2.1. Sampling

Water samples were collected during three oceanographic cruises conducted within the framework of the AegeanMarTech project in October 10–12th 2013, March 22–24th 2014 and July 15–18th 2014. Samples were taken from seven stations (AMT01 to AMT07) located along a north-south transect in the NE Aegean Sea and the vicinity of the Dardanelles Straits (Fig. 1; Table 1) at 6 or 7 standard depths, according to the water column depth of each station (Table 1), within the euphotic zone (0–100 m). In all cases, samples were collected for the determination of TEP, particulate organic carbon (POC) and chlorophyll-*a* (TChl*a*) concentrations, and bacterial production (BP) estimation. Conductivity/temperature/depth (CTD) profiles were re-

**Table 1**
Location (in decimal degrees) and characteristics of the sampled stations in the NE Aegean Sea frontal area, along with the corresponding sampling depths during the three campaigns.

| Station | Location | | Water depth (m) | Sampling depth (m) |
|---|---|---|---|---|
| | Lat. N | Lon. E | | |
| AMT01 | 40.3325 | 25.4585 | 280 | 3, 10, 20, 30, 50, 75, 100 |
| AMT02 | 40.2496 | 25.4460 | 900 | 3, 10, 20, 30, 50, 75, 100 |
| AMT03 | 40.1081 | 25.4351 | 90 | 3, 10, 20, 30, 50, 75, 85 |
| AMT04 | 40.0602 | 25.5394 | 67 | 3, 10, 20, 30, 50, 63 |
| AMT05 | 39.9477 | 25.6815 | 76 | 3, 10, 20, 30, 50, 73 |
| AMT06 | 39.7881 | 25.5448 | 88 | 3, 10, 20, 30, 50, 75, 85 |
| AMT07 | 39.6459 | 25.5919 | 216 | 3, 10, 20, 30, 50, 75, 100 |