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Seasonal variations of picophytoplankton density in Izmit Bay of the Sea of Marmara

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ABSTRACT

Izmit Bay is the northeast extent of the Sea of Marmara, consisting of two different water bodies. Vertical mixing primarily occurs during winter and thermal stratification takes place in summer. The bay is generally exposed to considerable anthropogenic inputs and industrial discharges. The picophytoplankton (P-Phyto) communities in Izmit Bay and their correlations with physicochemical parameters were studied monthly at mid-section stations and seasonally at coastal stations in 2012 within the context of the present study. During these studies, P-Phyto abundances were relatively low during the winter and the spring. At the same time, they were significantly high in the summer and the autumn. The significant statistical relationships between water temperature and cell abundance showed the discriminative impact of the temperature on population dynamics. Generally, the dominant group of P-Phyto was Picocyanobacteria (P-Cyan), especially in the warm periods.

1. Introduction

Picophytoplankton (P-Phyto) communities (≤2 μm) consist of autotrophic (eukaryotic; P-Euk and prokaryotic; P-Cyan) small-sized phytoplankter cells. *Prochlorococcus* (*Pro*) and *Synechococcus* (*Syn*) are the two main components of P-Cyan. P-Phyto contribute at least 10% to total global aquatic net primary productivity (Raven, 1984). They dominate primary production (≥50% of total biomass) in oligotrophic open ocean waters (Agawin et al., 2000). Numerous studies show the importance of P-Phyto communities in marine environments (Agusti et al., 2019; Calvo-Diaz et al., 2008; Schloss et al., 2008; Wilmotte et al., 2002). Recent studies underline the importance of P-Phyto dynamics in estuaries, bays, and eutrophic coastal areas as well (Veldhius et al., 2005; Caroppo et al., 2006; Gaulke et al., 2010; Mukhanov et al., 2016; Pulina et al., 2017; Brewin et al., 2019). The quantity and the quality of the studies have been rising as flow cytometry and molecular techniques are integrated (Moran et al., 2010; Buitenhuis et al., 2012; Pan et al., 2013; Brewin et al., 2019; Wei et al., 2019). It is also essential to understand small-sized phytoplankton successions since recent studies show that they can affect bacteria, microalgae, and fish larvae negatively via their allelopathic activities (Sliwinska-Wilczewska et al., 2018).

The Sea of Marmara is located in the north-western part of Turkey, between the Black Sea and the Aegean Sea. Our study area, Izmit Bay, is respected as the north-eastern extent of the Sea of Marmara. The bay is situated right in the center of the metropolitan region, widely known as an industrial area in Turkey. That means the bay's ecosystem is generally exposed to considerable anthropogenic inputs and industrial discharges (Okay et al., 1998; Yasar et al., 2001; Pekey et al., 2004; Ediger et al., 2012; Tolun et al., 2012; Tan and Aslan, 2020). Coastal areas are dynamic regions where the water circulation patterns may vary considerably. Terrestrial inputs (rivers, anthropogenic inputs) can instantly affect the water quality and affect planktonic populations. Blooms (particularly dinoflagellates and diatoms) are common phenomena in Izmit Bay (Tufekci et al., 2010). Their biological impacts associated with eutrophication in bays generally cause widespread concern (Li et al., 2019). For instance, estuaries and bays support abundant biodiversity via providing nursery grounds for organisms, such as valuable fish species. However, compared with the large size phytoplankton, no studies focused on P-Phyto distribution patterns in Izmit Bay. Understanding these patterns is also essential for a healthy food web and sustainable fishery in this region.

Prior studies on P-Phyto dynamics in Turkey were mainly focused in the Mediterranean (Polat, 2006; Uysal, 2006; Uysal and

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Koksalan, 2006; Polat and Uysal, 2009; Uysal and Koksalan, 2010) and in the Black Sea (Uysal, 2000, 2001, 2006; Feyzioglu et al., 2004; Kopuz et al., 2012; Feyzioglu et al., 2015; Aytan et al., 2018). Some studies revealed picoplankton in the Sea of Marmara (Uysal, 2006; Toklu-Alcili et al., 2020; Kocum, 2020), but little is known about the dynamics of P-Phyto. Moreover, there is no other study on P-Phyto distribution in Izmit Bay. However, it is known that coastal ecosystems are probably more sensitive to anthropogenic changes, activities, and population density (Pachauri and Meyer, 2014).

The present study provides the first comprehensive data on the seasonal distribution of P-Phyto communities in Izmit Bay. We aimed here (1) to assess abundances of two major components (P-Euk and P-Cyan) and suggest their annual succession capacities; (2) to analyze their pigment compositions; (3) to determine their correlations with the environmental parameters.

2. Materials and methods

2.1. Sampling area

Izmit Bay is the northeast extent of the Sea of Marmara (Fig. 1). Its shoreline length is 48 km, and its surface area is 18.300 km^2. The total water volume is 308 km^3. It is formed by three basins: (1) a relatively shallow eastern basin (max. depth ~30 m); (2) a middle basin (max. depth 160–200 m); (3) a western basin which connects the bay to the Sea of Marmara (max. depth: 150–300 m) (Algan et al., 1999). The hydrographic features of the bay follow an expected pattern by sharing similar characteristics with the Sea of Marmara. There are two different types of water bodies in Izmit Bay. The upper water mass originated from the Black Sea, while the deeper layer mass is derived from the Mediterranean Sea. Therefore, the bay shares the distinctive halocline (at 20–25 m) with the Sea of Marmara (Unluata et al., 1990; Besiktepe et al., 1994). Upper layer salinity is generally 22–24 psu, while the denser deeper layer salinity is about 38.5–39 psu (Unluata et al., 1990). A permanent halocline occurs between these layers and the thickness of water masses differs depending on seasonal and meteorological conditions. In winter, decreasing temperature (surface water cooling) and increasing effect of the wind cause vertical mixing, which leads to an increase in surface salinity and the upper layer gets thinner in this period. This means that no constant stratification depth exists in Izmit Bay, while there is one (25 m) in the Sea of Marmara (Oguz and Sur, 1986). For example, the upper layer thickness is 9 m in spring and 18 m in autumn in Izmit Bay (Algan et al., 1999; Oguz and Sur, 1986). The typical density differentiations also cause a two-layer flow system. The stratification becomes more significant in summer when the Black Sea originated lower saline waters enter the Sea of Marmara. The north-eastern and southwestern winds cause short-term rapid flows in upper and deeper layers to increase the exchange of water masses (KMM, Tubitak-MRC, 2013). The surface salinity is generally lower between spring and summer in agreement with seasonal stream discharges.

2.2. Sampling survey and laboratory analyses

Water samples were collected to analyze the nutrients, P-Phyto, chl-*a* and accessory pigment compositions. Sampling was performed monthly from January to December 2012 at three mid-section stations (eastern basin, EB; middle basin, MB; and western basin, WB) and seasonally (February, April, July November) at five coastal stations (C1, C2, C3, C4, C5) where some main streams meet the bay (Fig. 1). EB was the shallowest mid-section station (max depth: 25 m), while MB was the deepest (max depth: 80 m) and the maximum depth of WB was 50 m. Sampling depths for mid-section stations were as follows: **EB**–0.5 m, 10 m, 15 m, 20 m; **MB** and **WB**–0.5 m, 10 m, 20 m, 30 m. Coastal sampling was performed only at the surface: **C1**, **C2**, **C3**, **C4**, **C5**–0,5 m.

Water transparency was measured with a Secchi disk and temperature and conductivity were measured with a CTD on the cruise (Electrometric method, S.M. 2510 and 2520B/2005). Water samples were collected using Niskin bottles. The samples for nutrient analysis were put into pre-cleaned (with 10% HCl) bottles and stored at 4 °C until the analysis, usually within 24 h. Nutrient concentrations (NO_3+NO_2–N, o–PO_4–P) were analyzed on a Skalar autoanalyzer by the colorimetric method as described in specific guidelines (APHA, 1989; ASTM, 1990).

The P-Phyto samples (50 ml water) were collected in dark-colored bottles fixed with 1.25 ml–25% glutaraldehyde (final concentration 0.625%) and kept at 4 °C until the analysis, usually within 48 h. They were shaken and homogenized before counting. 10 ml of water was filtered through 0.2 μm pore-sized dark polycarbonate nuclepore membrane filters under pressure <5 atm for each (Li and Wood, 1988). 200 μl acridine orange solution was added when 5 ml of water remains to dye the DNA and RNA content (Hobbie et al., 1977). We classified picoeukaryotic and picoprokaryotic cells as groups by the following technique. Immersion oil was put on filters to prepare the preparats. P-Phyto cells were counted with Nikon TE 2000 + Super High-Pressure Mercury Lamp Power Supply according to the cell counting method, which enables many very small (0.2 -1 μm) faintly fluorescing cells can

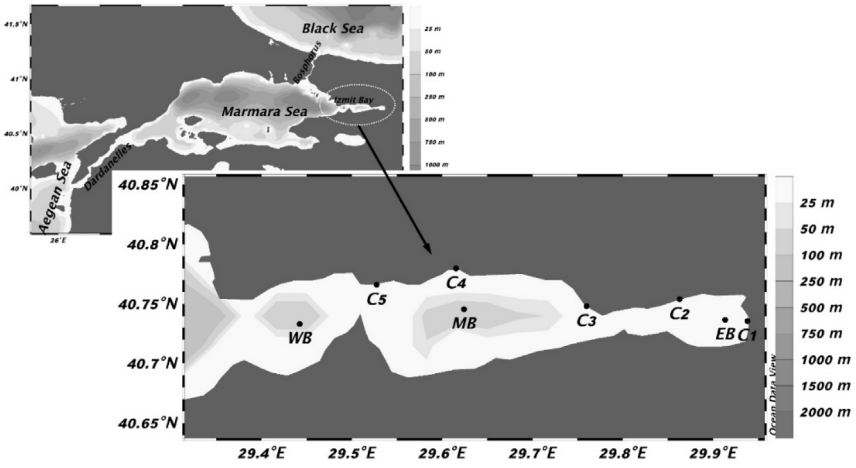

Fig. 1. Sampling stations in the Izmit Bay.

be seen (Jones, 1974; Stockner and Antia, 1986; Callieri et al., 1996; Callieri, 2008). 100X fluorescence objective, blue and green filter blocks were used (B–2 A blue excition — DM 505, EX 450–490, BA 520) ve G–1 A (green excition — DM 575, EX 546/10, BA 580). Blue excition block exposed the cells with red autofluorescence because of chl-*a* (and its derivates) excition. The ones with phycoerythrin contents appeared yellow and the ones which contain phycocyanin were seen faded red (Callieri, 2008). Green excition block exposed prokaryotes. The phycoerythrin-rich ones were seen with orange autofluorescence, while the phycocyanin-rich ones were red (Callieri, 2008). However, the sizes and the colors of the cells were not noted. Cell numbers of each field for both filters were written as a total of seen cells. At least 30 microscopic fields were chosen randomly for each filter and counted to estimate the abundance (Utermohl, 1958).

Chl-*a* was measured by using high performance liquid chromatographic method. Pigment analyses were carried out with HPLC (Agilent 1200 Series). Samples (0.3–1 L) were filtered through GF/F filters (25 mm; 0.7 μm pore size) and the filters were stored in liquid nitrogen until the analysis, usually within 1 week. Pigment extraction was carried out in 5 ml of 90% acetone for 1 min in a sonicator at 60 Hz. The extracts were kept at +4 °C overnight. The samples were centrifuged at 3500 rpm for 10 mins. 500 μl extract was filtered through 0.2 μm pore-sized Millipore filters for each. Finally, 500 μl ammonium acetate was added to each sample and analyzed by HPLC (Barlow et al., 1993). The system was calibrated with selected pigment standards every time it was open. Pigment concentrations were calculated according to the standard external equation (Jeffrey et al., 1997). Pigment classification was made as followed: Fucoxanthin, 19'hexanol fucoxanthin, and chl-*b* (FUC+19HEX+CHL.*b*) represented P-Euk (Wright and Jeffrey, 1987; Bjornland and Liaen, 1989; Barlow et al., 1993; Not et al., 2005). Zeaxanthin and divinyl chl-*a* (ZEA+DIV.*a*) represented P-Cyan (Bjornland and Liaen, 1989; Jeffrey et al., 1997).

The correlation between P-Phyto (P-Cyan and P-Euk) abundance and environmental parameters (temperature, salinity, Secchi disk depth, NO_3-NO_2-N, o-PO_4-P, chl-*a*, FUC+19HEX+CHL.*b*, ZEA+DIV.*a*) were considered according to the null hypothesis. A canonical correlation was used to evaluate multiple correlations between P-Phyto abundances and environmental parameters. All variables were log-transformed before analyses since none of them were usually distributed. All analyses were performed using SAS software (ver. 9.4, SAS Institute, Cary, NC, USA). Furthermore, a redundancy analyses (RDA) was applied to data in order to visualize and summarize linear relationships between P-Phyto (P-Cyan and P-Euk) abundance and environmental parameters. RDA analyses were performed using R (R Core Team, 2021).

3. Results

3.1. Physico-chemical parameters

The whole variation range of water temperature was between 6 to 26 °C. The lowest values were observed in February and the highest ones in July and August (Fig. 2). Besides, it was a constant value (14–17 °C) under 40 m at MB and WB. The top of the thermocline differed from 10 to 15 m at these stations. Salinity varied from 17 to 42 psu at all stations. EB was the shallowest among the mid-section stations. Thus, no remarkable halocline was observed due to mixing at EB. The top of the halocline was located between 10 and 30 m at MB and WB. It was also recorded that salinity occasionally decreased in the rainy season at coastal stations especially at C2 (16.6 psu — in April) (Fig. 3).

The Secchi disk depths varied between 1–10 m all across the bay and it was also observed that the values were low in the winter and the spring, whereas they showed an increasing trend in the summer and the autumn. EB, C1, C2, and C3 had the lowest values during the year.

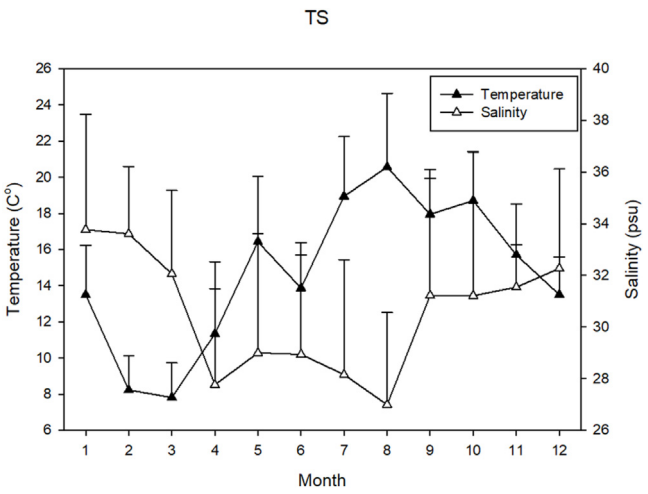

Fig. 2. Seasonal variation in average values of surface temperature and salinity in the middle section. Error bars are standard deviation with positive values ($n = 14$).

NO_3+NO_2–N values varied between 0.17–9.39 μM (max: WB - 50 m - June) at mid-section stations. The highest value of the upper layer (6.05 μM) was recorded in February at EB. The values were higher in the deeper layer than the halocline and the upper layers. Surface concentrations showed a decreasing trend from the eastern basin to the western. At the coastal stations, NO_3+NO_2-N values were measured between 0.17–58.0 μM. The highest values were observed in February, while the lowest ones (C1, C4) were in the spring and the autumn (Fig. 5). Surface o-PO_4-P concentrations showed similar trends with nitrogen compounds, but their amounts were relatively lower at the mid-section stations (Fig. 4). Maximum o–PO_4–P was detected in December at EB at the bottom (20 m). The values varied from 0.1 to 6.29 μM at coastal stations (max: C3–Feb; C2–Oct/min: C1 and C4–July) (Fig. 5).

3.2. Picophytoplankton abundance

At EB, P-Phyto abundances were high in upper layers during the winter and the spring, whereas the cells preferred deeper layers as the summer began (Fig. 4). High densities of cells were generally observed at the surface in the autumn. However, there was an exception in October at 20 m (7.2×10^8 cells/L). P-Euk dominated the surface in the winter and the spring. On the other hand, P-Cyan dominated the communities with the beginning of the summer (Fig. 7). P-Phyto dynamics at MB reflected a similar trend with the ones at EB (Fig. 6). However, a significant increase in the cell abundance was recorded in May at the surface (4.5×10^7 cells/L). Cell numbers increased almost three times with the beginning of June at MB (min: July — 30 m–2.41×10^6 cells/L; max: Aug — 20 m–13.3×10^7 cells/L). The distributions of cell abundance indicated similar characteristics at all mid-section stations (Fig. 6). Most picophytoplankter cells preferred to be at the surface along with the winter and the summer at WB (Fig. 6). Then they began to increase in deeper layers starting from June (min: July — 30 m–2.1×10^6 cells/L; max: Aug — 10 m–7.4×10^6 cells/L). P-Phyto communities of all mid-section stations (especially the surface and the upper layer communities) were highly dominated by P-Euk for the entire winter and spring. Then they replaced with P-Cyan as the summer began (Fig. 7). Cell

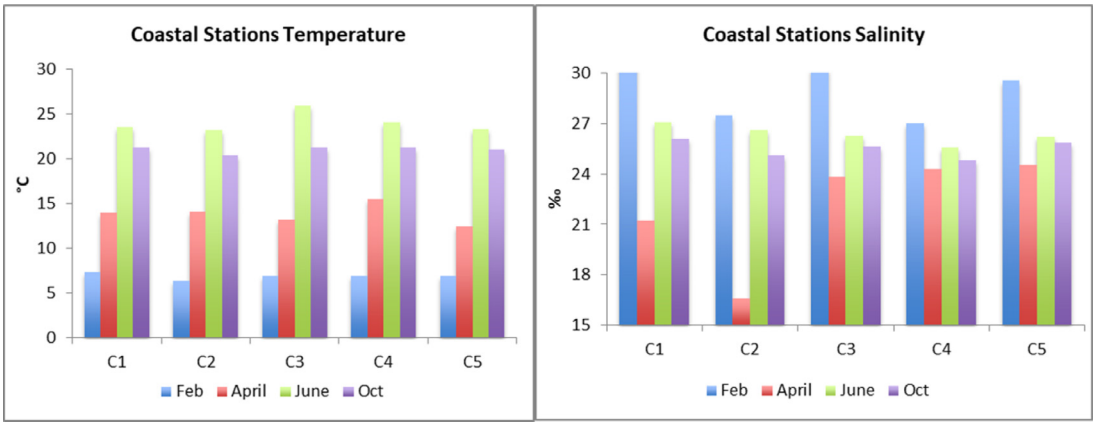

Fig. 3. Seasonal variation in temperature and salinity values at the coastal stations.

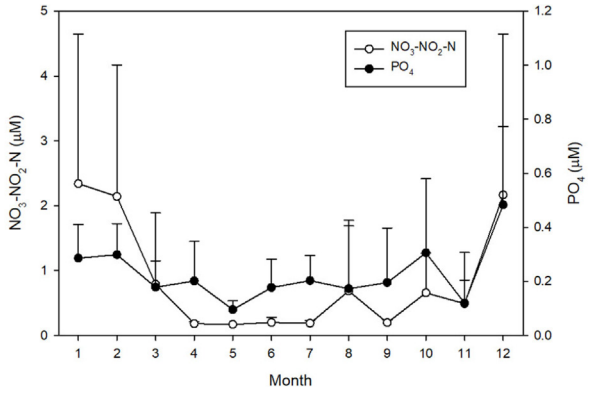

Fig. 4. Monthly variation in average values of surface NO_3+NO_2–N and o–PO_4–P in the middle section. Error bars are standard deviation with positive values ($n = 7$).

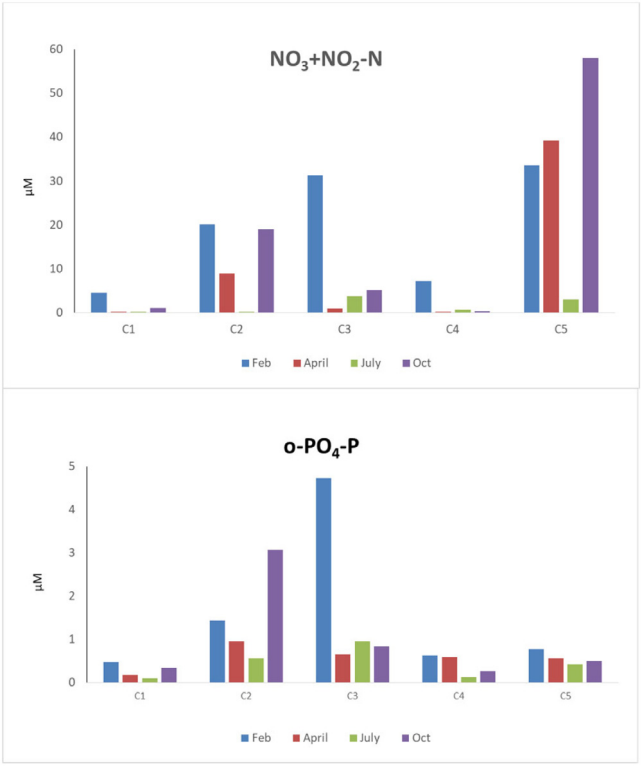

Fig. 5. Seasonal variation in NO_3+NO_2–N and o–PO_4–P values at the coastal stations.

abundances varied between 3×10^6 and 16.2×10^7 cells/L at the coastal stations and showed an increasing trend in the summer and the autumn (Fig. 8). P-Euk was the dominant group at all coastal stations throughout the winter and the spring; then, P-Cyan dominated the community for the rest of the year (Fig. 8). It was also noted that no cell smaller than 0.5 µm was identified with the microscopy at the coastal stations.

3.3. Pigment analyses

According to chl-*a* results at mid-section stations (0.01–8.9 µg/L), relatively high values were observed in the winter and the spring (Fig. 9). Chl-*a* maximum observed in upper layers along the first half of the year and then descended to the intermediate and bottom layer in the second half of 2012. The values showed a decreasing trend from the eastern basin to the western basin and the lowest ones in the entire water column were observed in October at EB (Fig. 9). At coastal stations, surface chl-*a* values varied between 0.74 and 9.2 µg/L (Fig. 8) and the high concentrations were recorded in the summer. It was also seen that there were dramatic decreases in chl-*a* values in the wintertime. The ZEA+DIV.*a*, which represented P-Cyan in the water column, was high in the middle and the bottom layers from the beginning of the spring (max: 0.66 µg/L, Oct — 20 m) at EB (Fig. 9). The FUC+19HEX+CHL.*b*, which represented P-Euk were measured high in the autumn and the winter in the upper layers. Low concentrations were detected in the summer period, especially at the surface and along the water column. The significant increase of P-Cyan (July — 15 m and Oct — 20 m) at EB was also confirmed by the pigment results. At MB, ZEA+DIV.*a* concentrations were high in the winter at the surface and at 10 m. It was also observed that the values were relatively high in the whole water column from the beginning of April (Fig. 9). FUC+19HEX+CHL.*b* concentrations were also high at the beginning of the spring, the autumn, and the winter (max:4.76 µg/L, May — surface). At WB, ZEA+DIV.*a* concentrations (0.01–10.38 µg/L) were measured relatively high in upper layers in the winter and the spring (Fig. 9). High values descended to the bottom layers along with the summer. FUC+19HEX+CHL.*b* concentrations in the winter and the spring were almost two times more than those measured in the summer and the autumn (Fig. 9). The growth of P-Cyan during the summer was also correlated with some pigment concentrations at WB. According to the pigment results, no DIV.*a* was detected at the coastal stations.

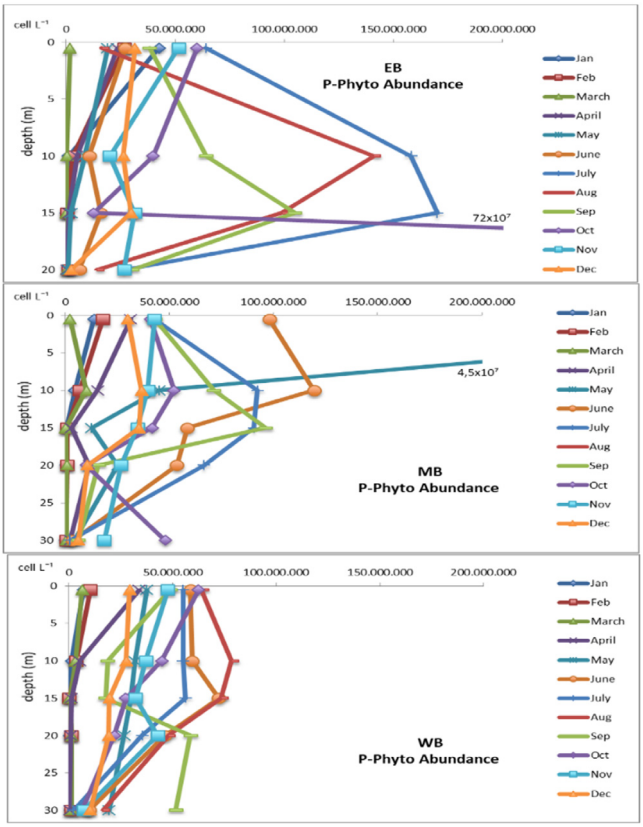

Fig. 6. Seasonal variation in P-Phyto abundances in the middle section.

In other words, measured ZEA+DIV.a concentrations as pigment markers of P-Cyan consisted of only ZEA at C1, C2, C3, C4, and C5. Concentrations indicated different trends among the coastal stations (Fig. 10). On the other hand, FUC+19HEX+CHL.*b* concentrations were relatively high in the summer and occasionally in the autumn at all coastal stations where the sampling was only performed at the surface.

3.4. Statistical analyses

According to the statistical analyses, the first and second canonical correlations were significant (p-value < 0.0001). Multivariate statistics (Wilks' Lambda, the Hotelling–Lawley Trace, and Roy's greatest root) with p-values (<0.0001) suggested rejecting the null hypothesis that all canonical correlations were zero in the population, confirming the results of the preceding likelihood ratio test. Correlations between the cell abundance and the canonical variables of the environmental parameters showed that P-Cyan and P-Euk were correlated with the environmental groups. RDA analyses showed that P-Euk was positively linked with spring and winter seasons both at coastal and mid-section stations, whereas, P-Cyan was positively linked with summer and autumn seasons both at coastal and mid-section stations. P-Euk showed strong negative correlation with depth and salinity, however, P-Cyan showed very little correlation with those variables. P-Cyan had a strong positive correlation with Secchi depth and temperature, and a negative correlation with Chl-a and FUC+19HEX +CHL.*b*, O-PO_4-P whereas P-Euk had a negative correlation with temperature and Secchi depth (see Fig. 11).

4. Discussion

Water temperature, nutrient concentrations, seasonal stratification, and microzooplankton pressure are significant factors affecting phytoplankton dynamics in marine systems (Mousseau et al., 1996; Veldhius et al., 2005; Mackey et al., 2009). The relationship between these parameters and cell abundances also presents the effects of climate change on planktonic communities (Behrenfeld et al., 2006). Climate change might affect their seasonal successions via the extended summer and stratification periods (Marcos and Tsimplis, 2008; Tsimplis et al., 2008). It also has been shown that P-Phyto has a considerable value as being a part of planktonic communities both in oligotrophic seas and nutrient-rich areas (Agawin et al., 2000). According to the results of some studies performed in Pensacola, Florida, in Virginia Bays, and Western Mediterranean (Murell and Lores, 2004; Gaulke et al., 2010; Mercado et al., 2021), it has been observed that P-Phyto communities are critical components of total phytoplankton which have to be considered as contributors to eutrophication.

The present study focused on the three mid-section stations (EB, MB, WB) and five coastal stations (C1, C2, C3, C4, C5 — where some main streams meet the bay) in Izmit Bay, the Sea of Marmara. The results generate the very first knowledge on P-Phyto ecology in the bay. Also, this study can be considered as an essential contributor to the P-Phyto data, which remains rare in offshore and coastal waters of the Sea of Marmara. Unfortunately, a significant amount of data on large size phytoplankton was lacking, and we could not compare our picophytoplankton data within the context of large size phytoplankton. Hence we were not able to make the quantitative and statistical analyses with the existing phytoplankton data. Generally, P-Phyto distribution at all stations was comparable with several other studies (Li, 1998; Mihalatou and Moustaka-Gouni, 2002; Uysal and Koksalan, 2006; Polat and Uysal, 2009). The densities were relatively low in the winter and the spring, and were high in the summer, especially towards the end of the summer. The effect of the temperature was statistically supported and this was following some other research (Hall and Vincent, 1994; Not et al., 2005; Kahyalar, 2007; Yucel, 2013; Pulina et al., 2017).

A conclusive correlation between the abundances of phytoplankton and picophytoplankton could not be reached because of the insufficient data. Nevertheless, according to the existing phytoplankton data (KMM, Tubitak-MRC, 2013) it was seen that the first phytoplankton bloom of 2012 occurred at the surface at EB in March. It was also recorded that P-Phyto formed a bloom. Both phenomena overlapped with the highest chl-*a* concentration among the mid-section stations throughout the study. Because of the significant relationship between P-Phyto abundance and chl-*a* concentrations, we can generally say that P-Phyto could maintain the same "bloomer" strategy with higher abundance during large size phytoplankton blooms as Mackey et al. (2009) suggested before. Besides, the highest P-Phyto as well as the highest P-Cyan abundance (EB - 20 m — 7.2×10^8 cell/L — Oct) coincided with one of the highest transparency values throughout the warm period. The statistical analysis already underlined the effect of light on the cell density during the extended summer. The cell abundance increased as long as the transparency increased. Increasing temperature and light in the summer period create favorable conditions for P-Cyan as they contain *zea*xanthin which is a photoprotective pigment. It leads them to be more resistant to stronger light conditions (Yucel et al., 2017).

Some studies suggested that temperature is an essential key factor for P-Phyto growth (Jiang et al., 2017; Mitbavkar and Anil, 2018). We also found significant positive correlations between cell abundance and temperature. Nevertheless, some others (Worden et al., 2004; Mukhanov et al., 2016) have not found any correlation between cell abundances and temperature, including the one which was performed in the Sea of Marmara (Toklu-Alcili et al., 2020). The present study showed that the

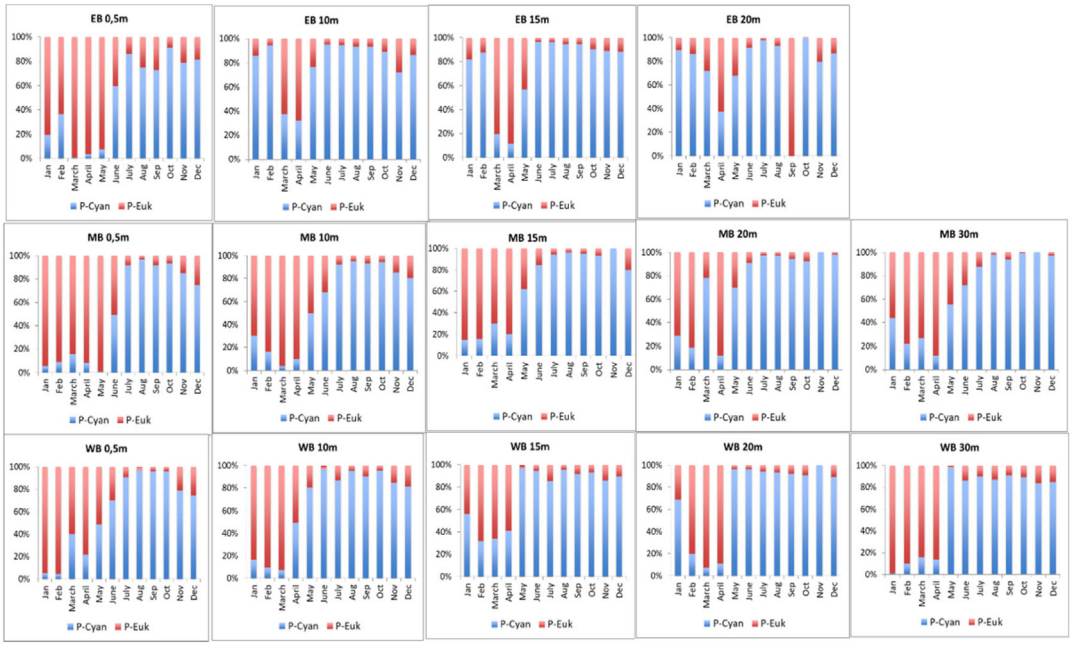

Fig. 7. Annual succession of P-Cyan/P-Euk in the middle section.

Fig. 8. Seasonal variation in P-Phyto abundances and annual succession of P-Cyan /P-Euk at the coastal stations.

dominant group of the warm periods was P-Cyan both at mid-section and at coastal stations as the RDA analysis also supported. This result has already been very well documented in the literature, where the temperature is indicated as a key factor controlling for P-Cyan growth (Ning et al., 2000; Bec et al., 2005; Collos et al., 2009; Pulina et al., 2017). Besides, P-Euk was abundant during cold periods both at mid-section and at coastal stations as RDA analysis also suggested. This case was in accordance with the results of a study from Alboran Sea (Amorim et al., 2016). A previous study implied that picoeukaryotic cells are ubiquitous in the marine environment, with the population maximum frequently occurring in low irradiance but high nutrient environments (Zhang et al., 2013). In particular, P-Euk can tolerate lower temperatures (Wei et al., 2019). Mukhanov et al. (2016) suggested

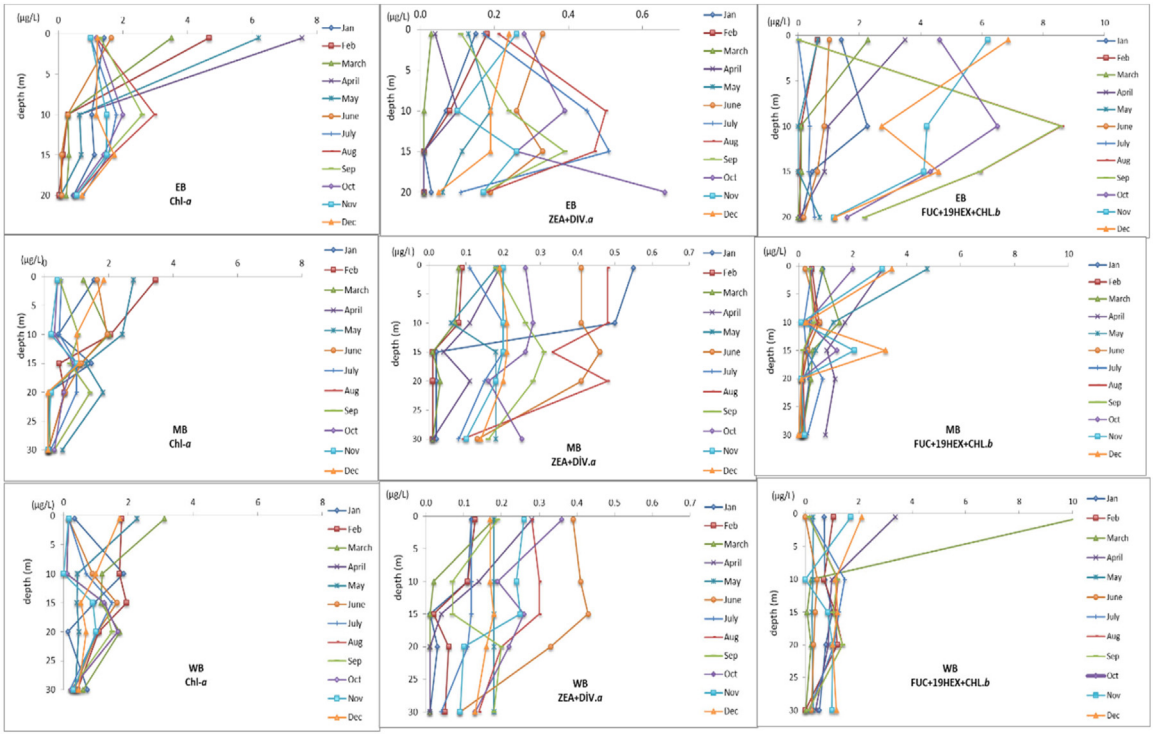

Fig. 9. Seasonal variation in pigment values in the middle section.

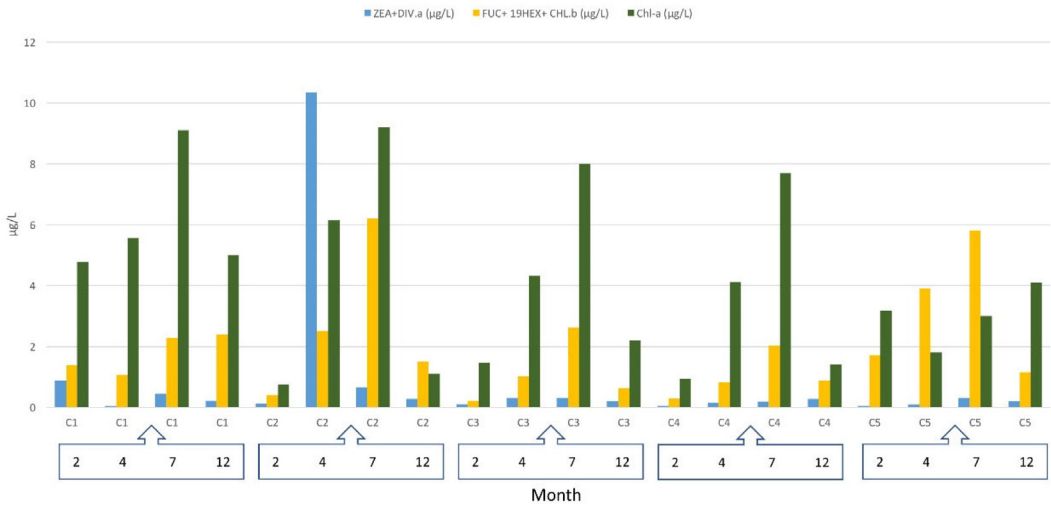

Fig. 10. Seasonal variation in pigment values at the coastal stations.

that P-Euk density was high in February and March, although there were not any reported statistical correlations between cell abundances and temperature. Our statistical analyses indicated that P-Cyan is more sensitive to temperature. In other words, P-Euk might become dominant while P-Cyan cells were reducing with the decreasing temperature. Relatively high P-Phyto (also P-Cyan) abundances at C1, C2, and C3 corresponded to the study by Amorim et al. (2016), which showed that P-Cyan were more abundant in coastal areas in summer and also corresponded with the one suggested that growth of P-Cyan was induced by high temperature (Salhi et al., 2018).

RDA analysis clearly indicated the negative correlation between P-Euk and salinity as also suggested by some other studies (Paerl et al., 2020; Liu et al., 2021). Because the salinity increased with the depth in the bay we can underline that P-Euk dominated upper layers at mid-section stations.

Significant positive correlations were observed between the pigments and the P-Phyto groups that they represented. Moreover, DIV.*a*, which is the most important pigment for *Prochlorophytes* (*Pro*), was absent at coastal stations. Therefore, its absence was interpreted that there was not any *Pro* cell in P-Cyan community in the coastal area during this study. This case was also supported by microscopic identification as no cell smaller than 0.5 µm was able to be seen while counting. In other words, prokaryotic coastal community might be consisting only of *Syn* cells in the bay and similar findings were reported before (Partensky et al., 1999b,a; Qiu et al., 2010; Liu et al., 2015; Li et al., 2019). *Pro* was not observed in a recent study in the Black Sea (Mukhanov et al., 2016) as well. In addition, Bemal and Anil (2019) suggested that *Syn* was 1–10 times more than *Pro* in Arabian Sea coastal waters. It was also indicated in a study

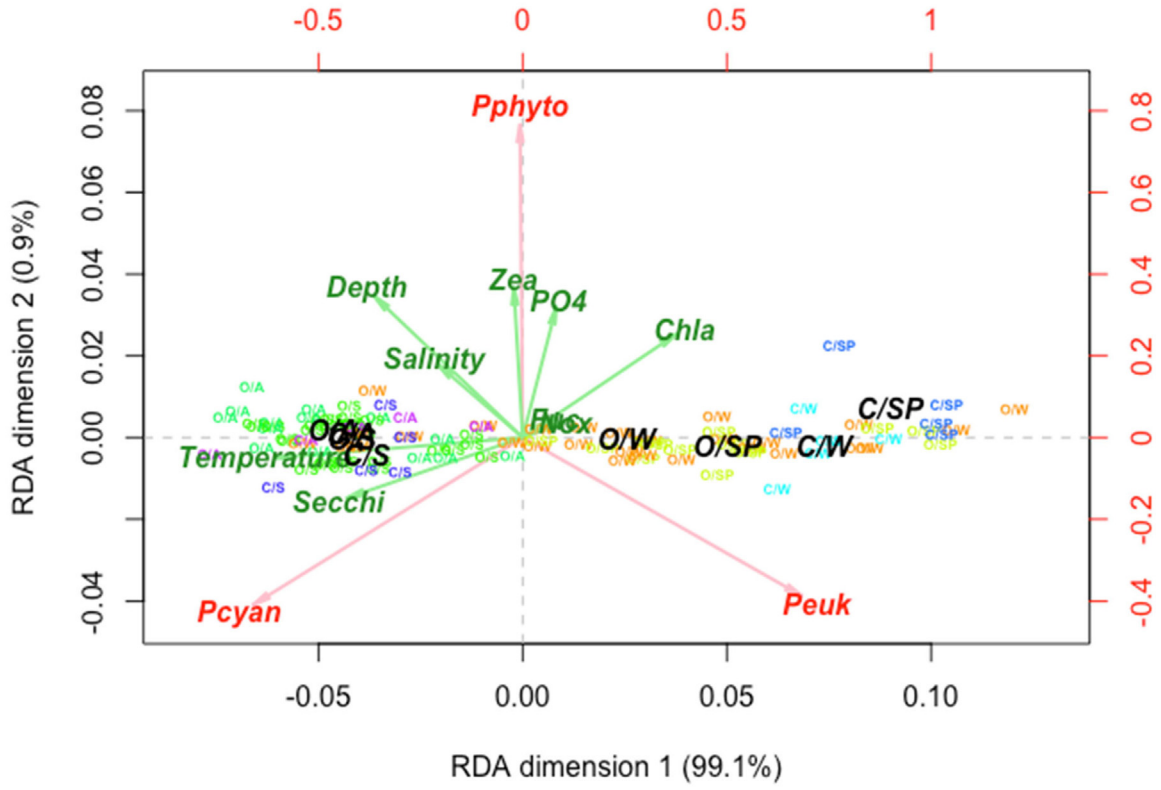

Fig. 11. RDA plot of P-Phyto (P-Cyan and P-Euk) abundance and environmental parameters. Interaction of stations (coastal (C) and mid-section (O)) and seasons (winter-W, spring-SP, summer-S, autumn-A) were grouped together and centroids of these groups marked as black. Abundance data marked as red, environmental variables marked as green.

performed in the southeastern Black Sea (Feyzioglu et al., 2004) that the abundance of *Syn* varied among the stations, but they were present in the photic zone at all stations. Besides, it is known that *Syn* can be subdivided into the open ocean and coastal phylogenetic clusters, which have no salinity requirements for growth (Dufresne et al., 2008; Sohm et al., 2015), and a study performed in the eastern Indian Ocean showed the presence of *Syn* cells like these (Wei et al., 2019). This present study suggests that the coastal *Syn* populations might be of them, but further analyses are certainly needed for conclusive proof. Although some flagellates may contain zeaxanthin, it is a distinguishing indicator for cyanobacteria. According to the results of simultaneously performed research (KMM, Tubitak-MRC, 2013), it was seen that no large size cyanobacterial cell was found in the middle section, and this supported the case that detected zeaxanthin might represent the picocyanobacterial community. Moreover, in a recent study, the zeaxanthin concentration peak coincided with *the Syn* peak (Mishra et al., 2020). Relatively high cell abundances during summer might be correlated with the presence of zeaxanthin, as suggested by Yucel before (2013).

Li (1998) has shown that nutrient concentrations are also important for P-Phyto dynamics. Some studies indicated that P-Cyan abundance (*Syn*) was high in coastal and nutrient-rich areas (Partensky et al., 1999b,a; Salhi et al., 2018). As mentioned before, we assume that the coastal P-Cyan community of Izmit Bay consisted of *Syn* regarding the pigment and counting data of the coastal stations. According to our statistical analysis, coastal community of this present study showed that it was dominated by P-Cyan in the summer and autumn. Polat and Uysal (2009) remarked that *Syn* cells were very abundant in the nutrient-rich part of the north-eastern Mediterranean Sea, highly affected by terrestrial inputs. Our statistical analysis also showed that the most significant correlation between nutrient (o-PO_4-P) and P-Phyto group (P-Cyan) was negative and this showed that o-PO_4-P might be consumed by P-Cyan.

5. Conclusion

A picophytoplankter cell is one of the most important model organisms which provides data to understand marine microbial processes and biological systems (Coleman and Chisholm, 2007). With the present study, the first findings on P-Phyto community of Izmit Bay have been discussed. P-Phyto abundances and the following environmental variables were significantly related: The key factor was change in temperature on the succession of small-sized phytoplankton in the middle section and the coastal part. P-Cyan was broadly the dominant group in warm periods whereas P-Euk dominated the winter and spring. It was statistically shown that salinity affected P-Euk cell growth negatively. Thus they preferred the less saline upper layer. Eventually, further and periodic research are needed, which should include biomass calculations, size fractioned pigment analyses, flow cytometric counting methods, and grazing and zooplankton pressure estimate to clarify the behaviors of picophytoplankton communities in Izmit Bay.

CRediT authorship contribution statement

Basak Sozer: Conceptualization, Data curation, Investigation, Visualization, Writing – original draft, Writing – review & editing. **Dilek Ediger:** Conceptualization, Data curation, Project administration. **Mustafa Mantikci:** Formal analysis, Software, Conceptualization, Data curation, Visualization. **Hakan Atabay:** Investigation, Data curation. **Meric Albay:** Supervision, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Agawin, N.S.R., Duarte, C.M., Agusti, S., 2000. Nutrient and temperature control of the contribution of picoplankton to phytoplankton biomass and production. Limnol. Oceanogr. 45, 591–600. http://dx.doi.org/10.4319/lo.2000.45.3.0591.

Agusti, S., Lubián, L.M., Moreno-ostos, E., Estrada, M., Duarte, C.M., 2019. Projected changes in photosynthetic picoplankton in a warmer subtropical ocean. Front. Mar. Sci. 5 (506), http://dx.doi.org/10.3389/fmars.2018.00506.

Algan, O., Altiok, H., Yuce, H., 1999. Seasonal variation of suspended particulate matter in two-layered İzmit Bay-Turkey. Estuar. Coast. Shelf Sci. 49, 235–250. http://dx.doi.org/10.1006/ecss.1999.0494.

Amorim, A.L., León, P., Mercado, J.M., Cortés, D., Gómez, F., Putzeys, S., Salles, S., Yebra, L., 2016. Controls of picophytoplankton abundance and composition in a highly dynamic marine system, the Northern Alboran Sea (Western Mediterranean). J. Sea Res. 112, 13–22. http://dx.doi.org/10.1016/j.seares.2016.02.005.

APHA, AWWA Ve WPCF, 1989. In: Greenberg, A.E., Trussel, R.R., Clesceri, L.S., Franson (Eds.), Standart Methods for the Examination of Water and Wastewater, 16 th. American Public Health Association, American Water Works Association and Water Environment Federation, Washington, D.C.

ASTM, 1990. Standard Guide for Performing Evaluations of Underground Storage Tank Systems for Operational Conformance. American Society for Testing Materials, Washington, D.C,

Aytan, U., Feyzioglu, A.M., Valente, A., Agirbas, E., Fileman, E.S., 2018. Microbial plankton communities in the coastal southeastern Black Sea: biomass, composition and trophic interactions. Oceanologia 60, 139–152. http://dx.doi.org/10.1016/j.oceano.2017.09.002.

Barlow, R.G., Mantoura, R.F.C., Gough, M.A., Fileman, T.W., 1993. Pigment signatures of the phytoplankton composition in the northeastern Atlantic during the 1990 spring bloom. Deep Sea Res. Part II: Top. Stud. Oceanogr. 40 (1–2), 459–477. http://dx.doi.org/10.1016/0967-0645(93)90027-K.

Bec, B., Husseini-Ratrema, J., Collos, Y., Souchu, P., Vaquer, A., 2005. Phytoplankton seasonal dynamics in a mediterranean coastal lagoon: emphasis on the picoeukaryote community. J. Plankton Res. 27, 881–894. http://dx.doi.org/10.1093/plankt/fbi061.

Behrenfeld, M.J., O'Malley, R.T., Siegel, D.A., Mcclain, R., Sarmiento, J.L., Feldman, G.C., Milligan, A., 2006. Climate-driven trends in contemporary ocean productivity. Nature 444, 752–755. http://dx.doi.org/10.1038/nature05317.

Bemal, S., Anil, A.C., 2019. Picophytoplankton *Synechococcus* as food for *nauplii* of *Amphibalanus amphitrite* and *Artemia salina*. Hydrobiologia 835, 21–36.

Besiktepe, S., Sur, H., Ozsoy, E., Abdul Latif, M., Oguz, T., Unluata, U., 1994. The circulation and hydrography of the Marmara Sea. Prog. Oceanogr. 34, 285–334. http://dx.doi.org/10.1016/0079-6611(94)90018-3.

Bjornland, T., Liaen, S.S., 1989. Distribution patterns of caretenoids in relation to chromophyte phylogeny and systematics. In: The Chromophyte Algae: Problems and Perspectives. Clarendon Press, Oxford, pp. 37–61.

Brewin, R.J.W., Morán, X.A.G., Raitsos, D.E., Gittings, J.A., Calleja, M.L., Viegas, M., Ansari, M., AL-Otaibi, N., Huete-Stauffer, T.M., Hoteit, I., 2019. Factors regulating the relationship between total and size-fractionated chlorophyll-a in coastal waters of the red sea. Front. Microbiol. 10 (1964), http://dx.doi.org/10.3389/fmicb.2019.01964.

Buitenhuis, E.T., Li, W.K.W., Vaulot, D., Lomas, M.W., Landry, M.R., Partensky, F., Karl, D.M., Ulloa, O., Campbell, L., Jacquet, S., Lantoine, F., Chavez, F., Macias, D., Gosselin, M., Mcmanus, G.B., 2012. Picophytoplankton biomass distribution in the global ocean. Earth Syst. Sci. Data 4, 37–46. http://dx.doi.org/10.5194/essd-4-37-2012.

Callieri, C., 2008. Picophytoplankton in freshwater ecosystems: The importance of small-sized phototrophs. Freshwater Rev. 1 (1), 1–28. http://dx.doi.org/10.1608/FRJ-1.1.1.

Callieri, C., Amicucci, E., Bertoni, R., Voros, L., 1996. Fluorometric characterization of two picocyanobacteria strains from different underwater light quality. Int. Rev. Gesamten Hydrobiol. 81, 13–23. http://dx.doi.org/10.1002/iroh.19960810103.

Calvo-Diaz, A., Moran, X., Suarez, L., 2008. Seasonality of picophytoplankton chlorophyll a and biomass in the central Cantabrian Sea, southern Bay of Biscay. J. Mar. Syst. 72, 271–281. http://dx.doi.org/10.1016/j.jmarsys.2007.03.008.

Caroppo, C., Turicchia, S., Margheri, M.C., 2006. Phytoplankton assemblages in coastal waters of the northern Ionian Sea (eastern Mediterranean), with special reference to cyanobacteria. J. Mar. Biol. Assoc. UK 86, 927–937. http://dx.doi.org/10.1017/S0025315406013889.

Coleman, M.L., Chisholm, S.W., 2007. Code and context: Prochlorococcus as a model for cross-scale biology. TIM 15 (9), 398–407. http://dx.doi.org/10.1016/j.tim.2007.07.001.

Collos, Y., Bec, B., Jauzein, C., Abadie, E., et al., 2009. Oligotrophication and emergence of picocyanobacteria and a toxic dinoflagellate in Thau lagoon, southern France. J. Sea Res. 61, 68–75. http://dx.doi.org/10.1016/j.seares.2008.05.008.

Dufresne, A., Ostrowski, M., Scanlan, D.J., Garczarek, L., Mazard, S., Palenik, B.P., Paulsen, I.T., Tandeau de Marsac, N., Wincker, P., Dossat, C., Ferriera, S., Johnson, J., Post, A.F., Hess, W.R., Partensky, F., 2008. Unraveling the genomic mosaic of a ubiquitous genus of marine cyanobacteria. Alexis Genome Biol. 9, R90. http://dx.doi.org/10.1186/gb-2008-9-5-r90.

Ediger, D., Beken, C., Tufekci, V., Husrevoglu, S., Atabay, H., 2012. Monitoring of Water Quality in the Izmit Bay, INOC-CNRS. In: International Conference on Land-Sea Interactions in the Coastal Zone Conference Book, 06-08 2012-Lebanon, pp. 239-246.

Feyzioglu, A.M., Eruz, C., Yildiz, I., 2015. Geographic variation of picocyanobacteria *Synechococcus spp*. along the Anatolian Coast of the Black Sea during the Late Autumn of 2013. Turkish J. Fish. Aquatic Sci. 15, 465–469.

Feyzioglu, A.M., Kurt, I., Boran, M., Sivri, N., 2004. Abundance and distribution of cyanobacteria *Synechococcus spp* in the South-eastern Black Sea during 2001 summer. Indian J. Mar. Sci. 33 (4), 365–368.

Gaulke, A.K., Wetz, M.S., Paerl, H.W., 2010. Picophytoplankton: A major contributor to planktonic biomass and primary production in a eutrophic, riverdominated estuary, Estuarine. Coast. Shelf Sci. 90 (1), 45–54. http://dx.doi.org/10.1016/j.ecss.2010.08.006.

Hall, J.A., Vincent, W.F., 1994. Vertical and horizontal structure of the picophytoplankton community in a stratified coastal system of New Zeland. New Zeland J. Mar. Freshwater Res. 28, 299–308. http://dx.doi.org/10.1080/00288330.1994.9516617.

Hobbie, J.E., Daley, R.J., Jasper, S., 1977. Use of nuclepore filters for counting bacteria by fluorescence microscopy. Appl. Environ. Microbiol. 33 (5), 1225–1228. http://dx.doi.org/10.1128/AEM.33.5.1225-1228.1977.

Jeffrey, S.W., Mantouro, R.F.C., Wright, S.W., 1997. Phytoplankton Pigments in Oceanography. UNESCO, Paris-Fransa, pp. 74–75.

Jiang, X., Li, J., Ke, Z., Xiang, C., Tan, Y., Huang, L., 2017. Characteristics of picoplankton abundances during a *Thalassiosira diporocyclus* bloom in the Taiwan Bank in late winter. Mar. Pollut. Bull. 117, 66–74. http://dx.doi.org/10.1016/j.marpolbul.2017.01.042.

Jones, J.G., 1974. Some observations on direct counts of freshwater bacteria obtained with a fluorescence microscope. Limnol. Oceanogr. 19, 540–543. http://dx.doi.org/10.4319/lo.1974.19.3.0540.

Kahyalar, P., 2007. Seasonal Variations of Abundance and Biomass of Picoplanktonic *Synechococcus* on the Yumurtalik, Sugozu Coastline (MSc. Thesis). Cukurova University – Institute of Science, İskenderun Bay, Balcali, Adana, p. 01330.

KMM (Kocaeli Metropolitan Municipality), KMM Tubitak-MRC, 2013. Monitoring the Water Quality and Terrestrial Inputs in Izmit Bay and Developing Suggestions for Preventing Pollution, Project Final Report, 41470, Kocaeli, Gebze, TR.

Kocum, E., 2020. Autotrophic nanoplankton dynamics is significant on the spatio-temporal variation of phytoplankton biomass size structure along a coastal trophic gradient. Reg. Stud. Mar. Sci. 33, 100920. http://dx.doi.org/10.1016/j.rsma.2019.100920.

Kopuz, U.A., Feyzioglu, A.M., Agirbas, E., 2012. Picoplankton dynamics during late spring 2010 in the south-eastern black sea. Turkish J. Fish. Aquatic Sci. 12, 397–405. http://dx.doi.org/10.4194/1303-2712-v12_2_28.

Li, W.K.W., 1998. Annual average abundance of heterotrophic bacteria and synechococcus in surface ocean waters. Limnol. Oceanogr. 43 (7), 1746–1753.

Li, J., Chena, Z., Jing, Z., Zhou, L., Li, G., Ke, Z., Jiang, X., Liu, J., Liu, H., Tan, Y., 2019. Synechococcus bloom in the Pearl River Estuary and adjacent coastal area–with special focus on flooding during wet seasons. Sci. Total Environ. 692 (2019), 769–783. http://dx.doi.org/10.1016/j.scitotenv.2019.07.088.

Li, W.K.W., Wood, A.M., 1988. Vertical distribution of North Atlantic ultraphytoplankton: analysis by flow cytometry and epifluorescence microscopy. Deep Sea Res. Part A. Oceanogr. Res. Pap. 35 (9), 1615–1638. http://dx.doi.org/10.1016/0198-0149(88)90106-9.

Liu, J., Fu, B., Yang, H., Zhao, M.2., He, B., Zhang, X.H., 2015. Phylogenetic shifts of bacterioplankton community composition along the Pearl Estuary: the potential impact of hypoxia and nutrients. Front. Microbiol. 6 (64), http://dx.doi.org/10.3389/fmicb.2015.00064.

Liu, Q., Zhao, Q., Jiang, Y., Li, Y., Zhang, C., Li, X., Yu, X., Huang, L., Wang, M., Yang, G., Chen, H., Tian, J., 2021. Diversity and co-occurrence networks of picoeukaryotes as a tool for indicating underlying environmental heterogeneity in the Western Pacific ocean. Mar. Environ. Res 170, 105376. http://dx.doi.org/10.1016/j.marenvres.2021.105376.

Mackey, K.R., Rivlin, T., Grossman, A.R., Post, A.F., Paytan, A., 2009. Picophytoplankton responses to changing nutrient and light regimes during a bloom. Mar. Biol. 156, 1531–1546. http://dx.doi.org/10.1007/s00227-009-1185-2.

Marcos, M., Tsimplis, M., 2008. Comparison of results of AOGCMs in the Mediterranean Sea during the 21st century. J. Geophys. Res. 113 (C12), http://dx.doi.org/10.1029/2008JC004820.

Mercado, J.M., Cortes, D., Jakobsen-gomez, F., Garcia-Gomez, C., Quassia, S., Yebra, L., Ferrera, I., Valcarcel-Perez, N., Lopez, M., Garcia Munoz, R., Ramos, A., Bernardeau, J., Belando, M.D., Fraile-Nuez, E., Ruiz, J.M., 2021. Role of small-sized phytoplankton in triggering an ecosystem disruptive algal bloom in a Mediterranean hypersaline coastal lagoon. Mar. Pollut. Bull. 164, 111989. http://dx.doi.org/10.1016/j.marpolbul.2021.111989.

Mihalatou, H.M., Moustaka-Gouni, M., 2002. Pico, nano, microplankton abundance and primary productivity in a Eutrophic Coastal area of the aegean sea, mediterranean. Int. Review Hydrobiol. 87 (4), 439–456. http://dx.doi.org/10.1002/1522-2632(200207)87:4<439::AID-IROH439>3.0.CO;2-3.

Mishra, R.K., Senga, Y., Nakata, K., Mishra, S., Sahu, B.K., 2020. Spatio-temporal variation of *prochlorococcus* and phytoplankton community between Shimizu coast and Suruga bay. Northwest Pacific Ocean Reg. Studi. Mar. Sci. 33, 100890. http://dx.doi.org/10.1016/j.rsma.2019.100890.

Mitbavkar, S., Anil, A.C., 2018. Responses of the picophytoplankton community to temperature fronts in the northeastern arabian sea during the northeast monsoon. Cont. Shelf Res. 163, 44–53. http://dx.doi.org/10.1016/j.csr.2018.04.015.

Moran, X.A.G., Urrutia, A.L., Calvo-Diaz, A., Li, W.K.W., 2010. Increasing importance of small phytoplankton in a warmer ocean. Global Change Biol. 16 (3), 1137–1144. http://dx.doi.org/10.1111/j.1365-2486.2009.01960.x.

Mousseau, L., Legendre, L., Fortier, L., 1996. Dynamics of size fractionated phytoplankton and trophic pathways on the Scotian Shelf and at the shelf break, Northwest Atlantic. Aquat. Microb. Ecol. 10, 149–163. http://dx.doi.org/10.3354/ame010149.

Mukhanov, V.S., Rylkova, O.A., Churilova, T.Y., Sakhon, E.G., Pimenov, N.V., 2016. Structure and seasonal trophodynamics of picophytoplankton in sevastopol bay and adjacent waters (the black sea). Microbiology (ISSN: 0026-2617) 85 (5), 553–561. http://dx.doi.org/10.1134/S002626171605012X.

Murell, M.C., Lores, E.M., 2004. Phytoplankton and zooplankton seasonal dynamics in a subtropical estuary: importance of cyanobacteria. J. Plankton Res. 26 (3), 371–382. http://dx.doi.org/10.1093/plankt/fbh038.

Ning, X., Cloern, J.E., Cole, E.B., 2000. Spatial and temporal variability of picocyanobacteria Synechococcus sp. in San Francisco Bay. Limnol. Oceanogr. 45 (3), 695–702. http://dx.doi.org/10.4319/lo.2000.45.3.0695.

Not, F., Massana, R., Latasa, M., Marie, D., Colson, C., Eikrem, W., Alio, C.P., Vaulot, D., Simon, N., 2005. Late summer community composition and abundance of photosynthetic picoeukaryotes in Norwegian and Barents Seas. Limnol. Oceanogr. 50 (5), 1677–1686. http://dx.doi.org/10.4319/lo.2005.50.5.1677.

Oguz, T., Sur, H.I., 1986. A Numerical Modelling Study of Circulation in the Bay of izmit. Final Report, Tubitak-MRC - Chemistry Department Publication, Turkey, pp. 187–197.

Okay, S.O., Egesel, L., Tufekci, V., Morkoc, E., Gaines, A., 1998. Investigation of three wastewaters entering İzmit bay (Turkey) by means of batch and chemostat culture algal bioassays. Mar. Environ. Res. 46 (1998), 283–288. http://dx.doi.org/10.1016/S0141-1136(97)00115-3.

Pachauri, R.K., Meyer, L.A., 2014. Climate Change 2014 Synthesis Report, Geneva, Switzerland.

Paerl, R.W., Venezia, R.E., Sanchez, J.J., et al., 2020. Picophytoplankton dynamics in a large temperate estuary and impacts of extreme storm events. Sci. Rep. 10, 22026. http://dx.doi.org/10.1038/s41598-020-79157-6.

Pan, X., Wong, G.T.F., Ho, T.Y., Shiah, F.K., Liu, H., 2013. Remote sensing of picophytoplankton distribution in the northern South China Sea. Remote Sens. Environ. 128, 162–175. http://dx.doi.org/10.1016/j.rse.2012.10.014.

Partensky, F., Blanchot, J., Vaulot, D., 1999a. Differential distribution and ecology of *Prochlorococcus* and *Synechococcus* in oceanic waters: a review. Microbiol. Mol. Biol. Rev. 63, 106–127.

Partensky, F., Hess, W.R., Vaulot, D., 1999b. Prochlorococcus, a marine photosynthetic prokaryote of global significance. Microbiol. Mol. Biol. Rev. 63 (1), 106–127. http://dx.doi.org/10.1128/MMBR.63.1.106-127.1999.

Pekey, H., Karakas, D., Ayberk, S., Tolun, L., Bakoglu, M., 2004. Ecological risk assessment using trace elements from surface sediments of Izmit Bay (Northeastern Marmara Sea). Mar. Pollut. Bull. 48, 946–953. http://dx.doi.org/10.1016/j.marpolbul.2003.11.023.

Polat, S., 2006. Size fractionated distribution of the phytoplankton biomass in the İskenderun Bay, northeastern Mediterranean Sea. Fresenius Environ. Bull. 15, 417–423.

Polat, S., Uysal, Z., 2009. Abundance and biomass of picoplanktonic *Synechococcus* (Cyanobacteria) in a coastal ecosystem of the northeastern Mediterranean, the Bay of İskenderun. Mar. Biol. Res. 5 (4), 363–373. http://dx.doi.org/10.1080/17451000802512275.

Pulina, S., Satta, C.T., Padedda, B.M., Bazzoni, A.M., Sechi, N., Lugliè, A., 2017. Picophytoplankton seasonal dynamics and interactions with environmental variables in three Mediterranean Coastal lagoons. Estuaries Coasts 40 (2017), 469–478. http://dx.doi.org/10.1007/s12237-016-0154-5.

Qiu, D.J., Huang, L.M., Zhang, J.L., Lin, S., 2010. Phytoplankton dynamics in and near the highly eutrophic Pearl River estuary, South China Sea. Cont. Shelf Res. 30, 177–186. http://dx.doi.org/10.1016/j.csr.2009.10.015.

R Core Team, 2021. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, https://www.R-project.org/.

Raven, J.A., 1984. Energetics and Transport in Aquatic Plants. In: MBL Lectures in Biology, vol. 4, Alan R. Liss, New York.

Salhi, N., Trikia, H.Z., Molineroc, J.C., Laabird, M., Sehlie, E., Bellaaj-Zouarie, A., Yahiab, N.D., Yahia, O.K.D., 2018. Seasonal variability of picophytoplankton under contrasting environments in northern Tunisian coasts, southwestern Mediterranean Sea. Mar. Pollut. Bull. 129 (2), 866–874. http://dx.doi.org/10.1016/j.marpolbul.2017.10.029.

Schloss, I.R., Nozais, C., Mas, S., 2008. Picophytoplankton and nanophytoplankton abundance and distribution in the southeastern Beaufort Sea (Mackenzie Shelf and Amundsen Gulf) during Fall 2002. J. Mar. Syst. 74, 978–993. http://dx.doi.org/10.1016/j.jmarsys.2008.01.004.

Sliwinska-Wilczewska, S., Maculewicz, J., Felpeto, A.B., Latala, A., 2018. Allelopathic and bloom-forming picocyanobacteria in a changing world. p. 10. http://dx.doi.org/10.3390/toxins10010048, Toxins.

Sohm, J.A., Ahlgren, N.A., Thomson, Z.J., Williams, C., Moffett, J.W., Saito, M.A., Webb, E.A., Rocap, G., 2015. Co-occurring *Synechococcus* ecotypes occupy four major oceanic regimes defined by temperature, macronutrients and iron. ISME J. 1–13. http://dx.doi.org/10.1038/ismej.2015.115.

Stockner, J.G., Antia, N.J., 1986. Algal picoplankton from marine and freshwater ecosystems: A multidisciplinary perspective. Can. J. Fish. Aquat. Sci. 43 (12), 2472–2503. http://dx.doi.org/10.1139/f86-307.

Tan, I., Aslan, E., 2020. Metal pollution status and ecological risk assessment in marine sediments of the inner izmit bay. Reg. Stud. Mar. Sci. 33, 100850. http://dx.doi.org/10.1016/j.rsma.2019.

Toklu-Alcili, B., Polat, S., Balkis-Ozdelice, N., 2020. Temporal variations in the abundance of picoplanktonic *Synechococcus* (Cyanobacteria) during a mucilage event in the Gulfs of Bandırma and Erdek, Estuarine. Coastal Shelf Sci. 233, 106513. http://dx.doi.org/10.1016/j.ecss.2019.106513.

Tolun, L.G., Ergenekon, S., Hocaoglu, S.M., Donertas, A.S., Cokacar, T., Husrevoglu, S., Beken, C.P., Baban, A., 2012. Socioeconomic response to water quality: a first experience in science and policy integration for the izmit Bay Coastal system. Ecol. Soc. 17 (3), https://www.jstor.org/stable/26269083.

Tsimplis, M., Marcos, M., Somot, 2008. 21st century Mediterranean sea level rise: Steric and atmospheric pressure contributions from a regional model. Glob. Planet. Change 63 (2–3), 105–111. http://dx.doi.org/10.1016/j.gloplacha.2007.09.006.

Tufekci, V., Balkis, N., Beken, C., Ediger, D., Mantikci, M., 2010. Phytoplankton composition and environmental conditions of a mucilage event in the Sea of Marmara. Turkish J. Biol. 34, 199–210.

Unluata, U., Oguz, T., Latif, M.A., Ozsoy, E., 1990. Physical Oceanography of Sea Straits. Kluwer Academic Publishers, Netherland, pp. 25–60.

Utermohl, H., 1958. Zur Vervollkommnung der quantitativen Phytoplankton-Methodik. Mitt. Int. Ver. Theor. Angew. Limnol. 9, 1–38.

Uysal, Z., 2000. Pigment, size and distribution of *Synechococcus* spp. in the Black Sea. J. Mar. Syst. 24, 313–326. http://dx.doi.org/10.1016/S0924-7963(99)00092-5.

Uysal, Z., 2001. Chroococcoid cyanobacteria *Synechococcus* spp. in the black sea: pigments, size, distribution, growth and diurnal variability. J. Plankton Res. 23 (2), 175–190. http://dx.doi.org/10.1093/plankt/23.2.175.

Uysal, Z., 2006. Vertical distribution of marine cyanobacteria *Synechococcus* spp. In the Black, Marmara, Aegean, and eastern Mediterranean seas. Deep Sea Res. Part II: Top. Stud. Oceanogr. 53 (17–19), 1976–1987. http://dx.doi.org/10.1016/j.dsr2.2006.03.016.

Uysal, Z., Koksalan, İ., 2006. The annual cycle of *Synechococcus* (cyanobacteria) in the northern Levantine Basin shelf waters (Eastern Mediterranean). Mar. Ecol. 27, 187–197.

Uysal, Z., Koksalan, I., 2010. Synechococcus dynamics in the Levantine basin shelf waters (northeastern Mediterranean). Mediterranean Mar. Sci. 11 (2), 277–294. http://dx.doi.org/10.1111/j.1439-0485.2006.00105.x.

Veldhius, M.J.W., Timmermans, K.R., Croot, P., Wagt, B., 2005. Picophytoplankton; a comparative study of their biochemical composition and photosynthetic properties. J. Sea Res. 53 (1–2), 7–24. http://dx.doi.org/10.1016/j.seares.2004.01.006.

Wei, Y., Sun, J., Zhang, X., Wang, J., Huang, K., 2019. Picophytoplankton size and biomass around equatorial eastern, Indian Ocean. Microbiology Open. 8, e629. http://dx.doi.org/10.1002/mbo3.629, 1 of 11.

Wilmotte, A.I., Demonceau, C., Goffart, A., Hecq, J.H., Demoulin, V., Crossley, A.C., 2002. Molecular and pigment studies of the picophytoplankton in a region of the Southern Ocean (42–54°S, 141–144°E) in 1998. Deep Sea Res. Part II: Top. Stud. Oceanogr. 49 (16), 3351–3363. http://dx.doi.org/10.1016/S0967-0645(02)00087-5.

Worden, A.Z., Nolan, J.K., Palenik, B., 2004. Assessing the dynamics and ecology of marine picophytoplankton: The importance of the eukaryotic component. Limnol. Oceanogr. 49 (1), 168–179 q. http://dx.doi.org/10.4319/lo.2004.49.1.0168, by the American Society of Limnology and Oceanography, Inc..

Wright, S.W., Jeffrey, S.W., 1987. Fucoxanthin pigment markers of marine phytoplankton analysed by HPLC and HPLTC. Mar. Ecol. Prog. Ser. 38, 259–266. http://dx.doi.org/10.3354/MEPS038259.

Yasar, D., Aksu, A.E., Uslu, 0., 2001. Anthropogenic pollution in izmit bay: Heavy metal concentrations in surface sediments. Turk. J. Engin. Environ. Sci. 25, 299–313.

Yucel, N., 2013. Monthly Changes in Primary and Bacterial Productivity in the Northeastern Mediterranean Shelf Waters (PhD). Middle East Technical University- Marine Biology and Fisheries.

Yucel, N., Uysal, Z., Tugrul, S., 2017. Variability in phytoplankton pigment composition in mersin bay. Turkish J. Aquatic Sci. 32 (1), 49–70.

Zhang, X., Shi, Z., Liu, Q.X., Ye, F., Tian, L., Huang, X.P., 2013. Spatial and temporal variations of picoplankton in three contrasting periods in the Pearl River Estuary, South China. Cont. Shelf Res. 56, 1–12. http://dx.doi.org/10.18864/TJAS201705.