SEASONAL CHANGES IN SETTLING PARTICULATE MATTER ON THE EASTERN TURKISH COAST OF THE BLACK SEA

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ABSTRACT

Total mass flux (TMF), total organic matter (TOM), carbonate (CaCO₃), lithogenic matter, biogenic silica (BSi), organic carbon (Corg), organic nitrogen (Norg) fluxes and sedimentation rates were determined seasonally using a sediment trap deployed in oxic layer on eastern coast of the Black Sea from July 2002 to October 2003. TOM, CaCO₃, Corg and Norg percentages in surface sediment and chlorophyll-a concentration in seawater samples were also determined at the same station. The highest TMF was measured as 56.4 g m⁻² day⁻¹ during autumn. The maximum TOM and CaCO₃ percentages and chlorophyll-a values were, respectively, determined to be 12.60, 14.06% and 5.68 µg l⁻¹ during spring. The highest fraction of Corg was recorded to be 2.88% during summer. C/N ratios in the settling materials suggested that nitrogen input increased during winter. Corg rates decreased in sediment cross section depth. Generally, the percentages of CaCO₃, Corg and Norg were lower in the surface sediment than trap sediment samples, except TOM value at 0-2-cm sliced surface sediment, implying that organisms activity was present in the oxic layer. The lithogenic matter was the dominant component in the trap materials which ranged from 66 to 80% depending on seasonal variation related with river discharges. Evaluated with precipitation rate and wind speed data, sedimentation rate was mainly related with vertical fluxes.

KEYWORDS: Black Sea, chlorophyll-a, sediment trap, total organic matter, vertical particle flux.

INTRODUCTION

Sediment traps are used for the collection of settling particulate matter in seawater column. Sediment trap studies are important in quantitative and qualitative estimates of particulate fluxes, and a number of chemical, physical biological and hydrodynamic parameters. Flux estimates also depend on trap design, sample processes and analytical procedures [1]. In addition, bottom sediments have been widely used as environmental indicators for determination of many pollutants [2, 3].

Many contaminants are introduced into the Black Sea through rivers or by direct discharge of industrial, agricultural and municipal wastes [4]. Pollution levels in the Black Sea have increased due to oil pollution and air-borne contaminants. At the same time, coastal erosion is a serious problem along the Black Sea coast. The eastern Black Sea region has been exposed to severe coastal erosion and shoreline recession for the last 30 years [5]. It has been suggested that the release of large quantities of soil particles into the Black Sea is the result of high erosion [6].

The continental shelf of the eastern Black Sea coast is rather narrower than the northern coast. Thus, sedimentation velocity displays characteristic features from shallow to deep water on the eastern coast [7, 8].

Chlorophyll a (Chl-a), the main pigment of plants and photosynthetic organisms, is responsible for a considerable portion of primary productivity. Chl-a variations in the Black Sea are important, especially in upper, shallow water layers [9].

In previous studies, the sedimentation flux rates were determined in western and central Black Sea basins [10, 11]. However, no data on sedimentation rates from the eastern Turkish coast of the Black Sea have been published.

The main objectives of this study are (1) to determine quantitative and qualitative vertical particle flux and to examine seasonal variations in fluxes at a station on the eastern coast of the Black Sea, (2) to determine sedimentation rates, (3) to determine the total organic matter (TOM), CaCO₃, Corg and Norg percentages in surface sediment and Chl-a concentration in seawater samples at the same station, and (4) to compare the results with similar studies.
MATERIAL AND METHODS

A sediment trap was deployed 40 m below the sea surface and 30 m above the bottom (70 m depth) on the eastern Turkish coast of the Black Sea at 40°58.361′ N and 39°51.136′ E. The location of the sampling station is shown in Fig. 1.

Vertical flux of particulate matter was determined using a cylindrical fiberglass trap, which is a modified Hydro-Bios-type of 50 cm in diameter and 150 cm in height. The trap had a conical bottom ending in a 1000-ml polyethylene sample jar. To prevent in situ microbial degradation, the sampling cup was filled with a 5% buffered formaldehyde solution in filtered sea water before mooring the trap.

To determine seasonal variations, sinking particles were collected during four different seasons - summer (5-29 July 2002, Sm-02), winter (20 January to 20 February, Wn-03), spring (15 April to 9 May, Sp-03) and autumn (24 September to 31 October, At-03) - at the same depth in the sampling station.

Surface sediment samples were collected from a depth of 70 m at the same station using an Ekman-type grab in autumn (31 October 2003, AtD-03) and summer (2 July 2004, SmD-04). Sediment samples were sliced into 0-2, 0-4 and 0-8 cm layers with three replicates.

RESULTS AND DISCUSSION

Hydrography

Hydrographic investigations in the region have been carried out by Alkan et al. [35] (Fig. 2), in the same monthly periods between 2001 and 2003. One of the most important characteristics separating the Black Sea from other oceans is the huge anoxic basin below depths of 100-200 m. In our investigation, both sediment trap samples and surface sediment samples were taken from a precise oxic layer. Dissolved oxygen (DO) reaches the highest level in the winter period and there was no significant difference between shallow waters and 70 m depth (Fig. 2a). Distinct from huge anoxic basin, oxic Black Sea waters enable planktonic and other pelagic or demersal organisms’ activity. In early May, thermocline formation began at depths of 20-40 m. Temperature reached the lowest level below 60 m depth, and there were no seasonal changes below this depth (Fig. 2b). There were no seasonal significant differences in salinity at sediment trap deployment depth. Salinity levels increased after 50 m, but there is no halocline layer over the sediment trap deployment depth (Fig. 2c).

In the region, average current speed varies between 10 and 30 cm s⁻¹ [16] and geotropic eastward anticyclonic surface currents which is identified as the Trabzon Eddy [17] exceed about 30 cm s⁻¹. Also current speed is faster in autumn and winter than spring and summer in the region [18].

Settling particulate matter

The maximum total mass flux (TMF) value was found during At-03 period. At the same time, the precipitation rate reached a maximum value. On the other hand, the minimum TMF quantity was determined in Wn-03 while precipitation was not high during this period (Table 1), showing there was a close relationship between TMF and precipitation. Wind speed reached its highest average in autumn 2003 (Fig. 3), and terrigenic material may be transported by the wind. Other factors, such as current speed and lateral advection can also affect TMF values in the region.
FIGURE 2 - Monthly average of Dissolved Oxygen, Temperature and Salinity values of water column in 2002 (a, b, c) and Chl-a values in 2001 (d) at sampling station [35].

TABLE 1 - Average values of total mass flux (TMF), total organic matter (TOM), CaCO₃, biogenic silica (BSi), lithogenic matter (in dry weight) and precipitation rate for different seasons.

<table>
<thead>
<tr>
<th>Sampling period</th>
<th>TMF (g m⁻² d⁻¹)</th>
<th>TOM (g m⁻² d⁻¹)</th>
<th>CaCO₃ (%)</th>
<th>BSi (%)</th>
<th>Lithogenic matter (%)</th>
<th>Precipitation (mm d⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>05-29 July 2002 (Sm–02)</td>
<td>25.9</td>
<td>2.99</td>
<td>11.52 ± 0.10</td>
<td>1.87</td>
<td>7.21 ± 0.08</td>
<td>12.27</td>
</tr>
<tr>
<td>20 Jan-20 Feb 2003(Wn–03)</td>
<td>9.4</td>
<td>0.99</td>
<td>10.52 ± 0.24</td>
<td>0.84</td>
<td>8.93 ± 0.14</td>
<td>2.55</td>
</tr>
<tr>
<td>15 Apr-9 May 2003(Sp–03)</td>
<td>13.6</td>
<td>1.71</td>
<td>12.60 ± 0.12</td>
<td>1.90</td>
<td>14.06 ± 0.16</td>
<td>7.34</td>
</tr>
<tr>
<td>24 Sep-31 Oct 2003(At–03)</td>
<td>56.4</td>
<td>5.91</td>
<td>10.49 ± 0.04</td>
<td>4.58</td>
<td>8.13 ± 0.08</td>
<td>1.38</td>
</tr>
</tbody>
</table>
Anderson et al. suggested that 55-110 cm sedimentation were deposited during 1000 years along the southern Black Sea shelves [19]. In a previous study, maximum mass flux rates were calculated to be 21.729 and 3.596 g m$^{-2}$ day$^{-1}$ at 118 and 603 m depths, respectively, in the Otranto Strait area [20]. Maximum TMF has reached 3.88 g m$^{-2}$ day$^{-1}$ at 360 m depth in the Gulf of California after hurricanes [21]. In another study, mean sedimentation rate was found to be 162±7 g m$^{-2}$ day$^{-1}$ ranging from 44±6 to 281±46 g m$^{-2}$ day$^{-1}$ in Venezuelan coastal areas [22]. In the present study, the mean sedimentation rate was calculated to be 26±2 g m$^{-2}$ day$^{-1}$ at a depth of 40 m. In general, the range of the TMF values in this investigation partly agreed with studies in other coastal areas. On the other hand, sedimentation rates in the Black Sea central basin have been reported as 0.360 and <0.003 g m$^{-2}$ day$^{-1}$ during July and August in 1986, respectively, at a depth of 1071 m [23]. A previous study reported that sedimentary material carried from the margins of the Black Sea into the abyssal plain yielded sedimentation rates (for the uppermost sediment layer) as high as 25-30 cm per 1000 years [10]. In another study, according to age determinations, the deposition rate along the Turkish coast of the Black Sea was found as much as 80-90 cm per 1000 years [24]. Our results are very high compared to other works on the offshore and central Black Sea basin, but it is well-known that high energy dynamics in coastal regions are very different from the open sea owing to freshwater inflow and currents.

The highest fluxes of TOM and CaCO$_3$ were found during At-03. Seasonal variations in TOM values are quite similar to CaCO$_3$ values (r=0.97). Besides of planktonic inputs, high TOM values may related with terrigenic matter. It is known that the autumn peaks of CaCO$_3$ flux coincide with coccolith (e.g. *Emiliania huxleyi*) blooms [25, 26].

The highest quantity of the BSi in the trap samples was found in Sm-02. This value decreased, on average, by a factor of ~2 during Sp-03. It is obvious that composition of phytoplankton community is in relation with chlorophyll-a increases. Also diatoms increase related with biogenic silica because of their siliceous skeleton. In a previous study, the average BSi content in the sediment-water interface was determined at 7%, and this value decreased to 4% under the fluff layer surface sediment in open Black Sea [25]. In another study, biogenic silica at an upper trap ranged from 0.1 to 15% in the south Adriatic Sea [27].

The contribution of lithogenic matter in the trap samples changed depending on season. In a previous study, the lithogenic flux fraction was predominant at 100, 200 and 315 m, and lithogenic fraction ranged between 55 and 60% [28]. The authors also indicated that the trapped material consisted of fine, muddy particles due to lateral advection by water masses originating from the land. In the present study, the lithogenic matter fraction was higher than in the range of the figures. As a result, it can be stated that lateral advection of dense water increased, especially during autumn, depending on coastal erosion along the eastern Black Sea.

In the present study, the percentages of TOM and CaCO$_3$ in the 0–2 cm sliced surface sediment at 70 m depth during AtD-03 were higher than the 0-8 cm surface sediment and trap samples (Table 2).

In oxygenated ocean basins, organic-rich aggregates are rapidly consumed by detrivores and microorganisms at the sediment-water interface [25]. Therefore, the existence of higher values in the 0-2 cm compared to the 0-8 cm layer in surface sediment is expected. The result also showed that total organic matter is relatively high in the fluff layer on bottom sediment in the eastern Black Sea coast.

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**TABLE 2 - Percentage values of TOM and CaCO$_3$ (in dry weight) at cross-section depths in surface sediment.**

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>TOM</th>
<th>Sediment cross-section depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–2 cm</td>
<td>0–8 cm</td>
</tr>
<tr>
<td></td>
<td>0–2 cm</td>
<td>0–8 cm</td>
</tr>
<tr>
<td>31 October 2003 (AtD–03)</td>
<td>18.022 ± 2.116</td>
<td>9.134 ± 0.737</td>
</tr>
<tr>
<td>2 July 2004  (SmD–04)</td>
<td>-</td>
<td>7.388 ± 0.092</td>
</tr>
</tbody>
</table>

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![FIGURE 3 - Daily vector-averaged wind speeds at the weather station in Trabzon City (The data were provided by the State Meteorological Institute [36]).](image-url)
TABLE 3 - Percentage values of Corg and Norg (in dry weight) for different seasons in the trap samples.

<table>
<thead>
<tr>
<th>Sampling Period</th>
<th>Corg</th>
<th>Norg</th>
<th>C:N</th>
</tr>
</thead>
<tbody>
<tr>
<td>05 Jul – 29 Jul 2002</td>
<td>2.880 ± 0.008</td>
<td>0.086 ± 0.001</td>
<td>33.49</td>
</tr>
<tr>
<td>20 Jan – 20 Feb 2003</td>
<td>2.120 ± 0.006</td>
<td>0.240 ± 0.001</td>
<td>8.83</td>
</tr>
<tr>
<td>15 Apr – 9 May 2003</td>
<td>2.180 ± 0.006</td>
<td>0.140 ± 0.001</td>
<td>15.57</td>
</tr>
<tr>
<td>24 Sep – 31 Oct 2003</td>
<td>2.070 ± 0.005</td>
<td>0.083 ± 0.001</td>
<td>24.94</td>
</tr>
</tbody>
</table>

TABLE 4 - Percentage values of Corg and Norg (in dry weight) at cross-section depths in surface sediment.

<table>
<thead>
<tr>
<th>Sampling Date</th>
<th>0–2 cm</th>
<th>0–4 cm</th>
<th>0–8 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corg</td>
<td>2.170 ± 0.006</td>
<td>2.130 ± 0.006</td>
<td>1.830 ± 0.005</td>
</tr>
<tr>
<td>Norg</td>
<td>0.085 ± 0.001</td>
<td>0.110 ± 0.001</td>
<td>0.067 ± 0.001</td>
</tr>
</tbody>
</table>

In surface sediment, CaCO3 concentrations were found to range from 5 to 15% in the south coast of the Black Sea [7]. Our CaCO3 results in surface sediment were slightly higher compared to the general average for sediments from the south coast of the Black Sea.

Organic carbon and organic nitrogen

The highest percentage of Corg in trap samples was found during Sm-02. On the other hand, the highest percent contribution of Norg was determined during Wn-03. C/N ratios in settled particulate matter (Table 3) show a decrement during winter due to nitrogen input. Artificial (NPK) fertilizers are applied during late autumn or early winter at 100 g m⁻² to hazelnut crops in the eastern Black Sea region. C/N ratios may be affected by fertilizers.

The mean sinking percentage of Corg is lower than that reported for other coastal areas [29, 30]. Our data generally indicated that the sampling station in the eastern Black Sea coast is not eutrophic. On the other hand, the rate of eutrophication is gradually increasing at industrial hot-spots near sewage discharges in the region [31].

According to our surface sediment results, Corg values slightly decreased with sediment cross-sectional depth (Table 4).

Surface sediment Norg and Corg values were found to be 1.76 and 0.16%, respectively, at 97 m depth in Sinop Bay on the Turkish coast of the middle Black Sea region [32]. Corg values in surface sediment samples from the southern Black Sea shelf were between 0.13-3.09% [7]. In another study, Corg ranged from 0.69 to 1.92% at 71 m depth in the southern Black Sea [33]. In conclusion, similar studies in the Black Sea showed that the percentage of Corg in coastal or shelf bottom-sediments significantly varied.

Chlorophyll-a

The concentrations of Chl-a in shallow and 40 m deep water at the tested site decreased in a similar trend depending on the season. However, photosynthetic activity was higher in shallow water than at 40 m depth in May and February. In contrast, the highest Chl-a values were found in 40 m depth during July and October (Table 5).

In the eastern Black Sea surface water, Chl-a ranged from 0.33 to 12.76 µg l⁻¹ during November [34]. In a previous study [9], the range of Chl-a concentration was found to be 1-11 µg l⁻¹ in surface water of the Turkish Black Sea coast during 1990-1996. The authors also found a Chl-a concentration of 2.5 µg l⁻¹ for deep water during spring. In the same region, photosynthetic activity slightly decreased with depth, similar to our results, and maximum Chl-a concentration was found to be 7.6 µg l⁻¹ (Fig. 2d) in May [35]. These results are in agreement with the present study.

CONCLUSIONS

Despite the destructive effects of erosion on the eastern Black Sea coast, relatively high biogenic values were determined in the trap and bottom sediment samples, depending on seasonal densities of pelagic and benthic organisms. Due to riverine inflow, terrigenous material is the dominant component of sediment. Also anthropogenic and domestic agents affect TMF via the same pathway. According to precipitation rate and wind speed data, sedimentation is mainly related to vertical fluxes.

In the near future, these coasts will be exposed to increased threats from industries, such as fossil fuels, phosphates and oil, use of artificial fertilizers, insufficiently treated sewage and municipal waste combustion.

Our results on vertical particle fluxes show that more ancillary data (e.g., phosphorus flux, fecal pellet flux, phytoplankton composition etc.) are necessary to better understand the transfer and transport processes. Our results were limited in space, time and mooring depth; therefore, further sampling is needed to monitor seasonal and annual variations.
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