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A COMPARATIVE STUDY ON THE ABUNDANCE AND ELEMENTAL COMPOSITION OF SESTON IN THREE INTERCONNECTED BASINS: THE BLACK, THE MARMARA AND THE MEDITERRANEAN SEAS

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ABSTRACT

This work principally aims to contribute to the further understanding of abundance and elemental composition of particulate organic matter (POM) in the land-locked basins with different trophic states. We have evaluated measurements of particulate organic carbon (POC), particulate nutrients (PON, PP), dissolved inorganic nutrients (NOx, PO_4), chlorophyll-a (CHL-a), light penetration and transmission, salinity and temperature data obtained seasonally in the upper layer waters of the Black, Mediterranean and Marmara Seas since 1990. In this context, we have also examined the stoichiometric relationships between POC-PON, POC-PP, PON-PP and POC-CHL-a data pairs, measured in the euphotic zones of the three seas having different dissolved inorganic nutrient concentrations and variable N:P ratios. Based on these findings, we address ranges of spatial and seasonal changes in the abundance and elemental composition of POM in the three interconnected basins having different oceanographic characteristics.

The Black Sea is a unique, land-locked basin with an oxygenated upper layer of 100-150 m. The large water mass below the permanent pycnocline is anoxic and contains hydrogen sulphide throughout the year. Since its surface waters receive large nutrient loads via riverine discharges and precipitation, in addition to inputs from the nutricline by vertical mixing, the Black Sea is a typical example of the eutrophic seas. The %1 light depth is reached at shallower depths (10-15 m) in shelf regions and during bloom but at 40-45 m in the open sea during summer when the nutrient input to the system is at minimal levels. The Marmara Sea connects the Black Sea to the ocean system via the Mediterranean Sea. The two-layer counter flows in the Turkish Straits, Bosphorus and Dardanelles, have led to the formation of a distinct two-layer ecosystem in the Marmara basin. The physical and biochemical properties of the relatively thin (10-15m) upper layer over the Marmara basin are principally dominated by the brackish Black Sea inflow via the Bosphorus Strait. A strong, permanent and steep halocline separates the brackish surface layer from the saltier Mediterranean waters, occupying the deep basin with significantly modified biochemical properties. Since solar light can not penetrate the halocline in the Marmara basin, primary production is confined to the Marmara upper layer, including the halocline depths (15-30 m) in the summer months. The Sea of Marmara is also eutrophic because the nutrient-rich Black Sea inflow and land-based discharges (including rivers and surface run-off) feed the upper layer throughout the year. On the other hand, the eastern Mediterranean including the Aegean Basin is known to be an oligotrophic marine environment, due to very limited nutrient supply to its surface layer. Therefore, the euphotic zone may extend down to 100-120 m in late spring-early autumn period. However, in the Rhodes cyclonic region, the relatively nutrient rich deep waters may rise up to the surface in winter, deepening below 50-75 m in summer. Thus the nutrients supplied from the deeper layer result in coherent increases in the algal content of the euphotic zone of the Rhodes cyclone and its peripheries as compared to the living carbon component of POM in the anticyclonic regions of northeastern Mediterranean.

The Southern Black Sea: The particulate concentrations in the euphotic zone varied regionally and seasonally; the layer-averaged concentrations ranged between 5.5-28.6 μM for POC, 0.7-3.1 μM for PON, 0.034-0.115 μM for PP in 1990-1998. These values are comparable to the Black Sea offshore values obtained by different groups in the last decade. The particulate concentrations are generally high in the surface mixed layer, decreasing markedly below the euphotic zone to background levels of 1-4 μM for POC, 0.1-0.3 μM for PON and 0.01-0.03 μM for PP in the oxic/anoxic transition layer. In the suboxic-anoxic transition zone formed between the 16.0 and 16.2 density surfaces, the particulate profiles display a coherently rising trend and then reach the maximal levels in the upper depths of the sulphide-bearing water. The deep layer particulate peak is more pronounced for PP, especially in the rim currents where a fine particle layer (enriched in inorganic particles) is formed throughout the year.

In summer-autumn periods, when the POM abundance in the productive zone of the open sea is sustained mainly by regenerated nutrients, the POC:CHL-a ratios appear to be as high as 250-1000, implying detritus-dominated POM pool in the euphotic zone. Phytoplankton biomass (algal-C) estimated from the regression slopes of organic carbon vs. CHL-a were relatively low for this period, comprising merely 10-20 % of the total POC measured in the euphotic zone. Moreover, a deep CHL-a maximum (DCM) is observed at the base of the euphotic zone, when the upper layer is seasonally stratified and relatively poor in dissolved inorganic nutrients. Low POC values and very low rates of primary production at the DCM depths indicate light-limited algal growth, leading to more CHL-a synthesis per cell. This results in relatively low C :CHL-a ratios in the shade-adapted cells. Hence, the DCM in the Black Sea does not represent a net increase in the algal biomass. The

suggestion can also be confirmed by increased relative abundance of protein and chlorophyll, but not carbohydrate markers (obtained by pyrolysis/GC/MS technique) in subsurface chlorophyll maximum layers. Relatively low values of carbohydrate markers and remarkable change in protein composition in the suboxic waters and sulphidic water boundary imply increased contribution of bacterial production to the POM pool in the oxic/anoxic waters of the Black Sea. Very low NO_X/PO_4 molar ratios strongly suggest nitrogen-limited algal production in the open Black Sea for most of the year. However, the long-term particulate data show that this situation is less pronounced in the N:P ratio of the seston, ranging seasonally between 10 and 22. The N:P ratios, estimated from the slopes of the regression analyses were also comparable, ranging seasonally between 13 and 21. Interestingly, the average PON:PP ratio (14.7) is comparable to the Redfield ratio of 16, implying the presence of other labile nitrogen compounds (as DON or by fixing dissolved N_2) available for phytoplankton production, especially in the seasons of stratification. The NO_X/PO_4 ratio increases in the southern coastal surface waters influenced by riverine discharges, but increase in the sestonic N:P ratio is less remarkable, and generally ranges between 13 and 23.

The Sea of Marmara: In the euphotic zone, the depth-averaged particulate concentrations for the open sea range seasonally between 10-35 μM for POC, 0.4-4.5 μM for PON and 0.05-0.45 μM for PP, with the peak values in February- March as in the southern Black Sea and Mediterranean. The Marmara particulate values decrease steadily from the Bosphorus region to the Dardanelles exit, depending on the nutrient supply to the system. The concentrations are greater than in the open Black Sea and Mediterranean, but comparable to, or less than those measured in the Bosphorus region of the Black Sea. Not unexpectedly, the chemical composition of POM in the euphotic zone of the Marmara Sea is comparable to those of Black Sea surface waters, with a similar seasonality. This apparently indicates the influence of Black Sea inflow on the biochemical properties of the Marmara Sea surface waters. The particulate data collected since 1991 demonstrate a pronounced seasonal variation, which lead one to make classification as more and less productive seasons. Linear regression analyses of particulate data from the more productive periods indicate that POC:PP (98) and POC:PON (7.4) ratios are comparable to the Redfield Ratios, whilst PON:PP ratio being as low as 9.5, due to as yet undefined factors. Interestingly, similar low NO_3:PO_4 ratios appear in the Marmara deep waters, suggesting the particle snow to occur with low N:P ratios. During the spring bloom, the POC:CHL-a ratio from the regression is as low as 38 and almost 50 % of the total POC is composed of living phytoplankton, whereas, no significant correlation has been observed between POC and CHL-a parameters during the less productive late spring-early autumn period when the algal growth is mainly sustained by regenerated nutrients in the open sea. The strong halocline formed in the Marmara Sea limits POM snow to its lower layer waters as compared to the sinking rates in the Black Sea.

The Eastern Mediterranean Sea: The depth-averaged particulate concentrations in the euphotic zone of the Levantine Sea since 1990 are in the ranges of 1.44-5.18 μM for POC, 0.06-0.68 μM for PON and 0.01-0.037 μM for PP, at least 3-4 times less than in the Black and Marmara seas. Nevertheless, the coastal water concentrations (6.22-10.4 μM for POC, 0.63-1.03 μM for PON, 0.039-0.072 μM for PP) are comparable to the concentrations in the open Black Sea, indicating the importance of land-based nutrient inputs.

The elemental composition of the bulk seston derived from regression analysis of the particulate data is generally comparable to the Redfield ratios. However, N:P ratios may be as low as 10-12 during the early spring bloom, suggesting particle snow to deep waters to occur with abnormally low N:P ratios as compared to the nitrate to phosphate ratio (26-28) of the Levantine deep basin waters. The N:P ratios of the seston are variable and higher than the bloom ratios for most of the year when the surface waters are relatively poor in nutrients (especially reactive phosphate) and thus, algal biomass. POC:Chl ratios derived from the regressions principally range between 45 and 201, though the surface mixed layer ratios being abnormally high in summer due to very low algal biomass in the nutrient poor surface waters. In the Rhodes cyclone and its peripheries, when the surface waters become seasonally stratified, generally a DCM is formed at the base of the euphotic zone. In contrast to Black Sea, particulate profiles display characteristic maxima at depths coinciding mostly with the DCM layer. Consistently, the CHL markers, determined by pyrolysis-GC/MS technique exhibit the similar trend. According to the analysis results carried out for only one season (November 1996), the relative abundance of carbohydrate markers diminish remarkably through depth, while the relative concentration of proteins is almost constant. Hence, particulate C:N ratios become relatively low towards the base of the euphotic zone as observed in the Black Sea, suggesting the suspended organic matter in the light-limited waters to be produced *in-situ*, rather than sinking from the surface waters.