

NUTRIENT EXCHANGE FLUXES BETWEEN THE BLACK SEA AND MEDITERRANEAN THROUGH THE TURKISH STRAIT SYSTEM (MARMARA SEA, BOSPHORUS AND DARDANELLES)

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Abstract

A comprehensive set of data collected between 1990 and 2001 allows us to estimate the volume and nutrient fluxes in the Turkish Strait System (Bosphorus, Marmara Sea and the Dardanelles), which is characterized by contrasting hydrochemical properties originating from the adjacent seas, viz. the salty Northeastern Mediterranean and the brackish Black Sea. Nutrient exchange fluxes in the straits vary markedly with season, due to changes in both the concentrations and volume fluxes. The majority of the Black Sea nutrient input to the Marmara Sea accumulates in the lower layer of the latter and is then exported to the Black Sea via the salty Bosphorus underflow of Mediterranean origin.

Keywords : Eastern Mediterranean, Black Sea, Bosphorus, Dardanelles, Hydrology.

The Black Sea is connected to the Mediterranean through the Turkish Strait System, which has a two-layer flow regime and distinctly different hydro-chemical properties during the year [1]. The Black Sea inflow is nearly two-fold greater than the volume of the salty Marmara water flowing into the Black Sea on an annual basis [2]. The counterflows in the straits increase in spring-early summer and then weaken markedly during autumn, depending upon water balance conditions in the adjacent seas, especially fresh water input to the Black Sea [3]. Similarly, the nitrate and phosphate concentrations in the brackish Black Sea surface flow in the Bosphorus display drastic seasonality [4]. The concentrations increase by 10-50 fold from summer to late autumn and winter months; e.g., during the summer-early autumn period, when the consumption of nutrients via photosynthesis greatly exceeds their supply from external and internal sources, nitrate concentrations reach as low as 0.1-0.2 μM whilst phosphate values drop to 0.02-0.05 μM . During the bloom in the Western Black Sea, the inflow to the Marmara basin is poor in DIN and DIP.

The salty Mediterranean water enters the Marmara basin with very low nitrate and phosphate concentrations for most of the year; however, it is enriched by about 10-fold (nitrate: 8-12 μM ; phosphate: 0.7-1.2 μM) during its stay in the basin and reaches as far as the Western Black Sea with modified chemical properties.

The seasonal volume fluxes and associated nutrient concentrations compiled in Table 1 and 2 have been used to estimate seasonal DIN and DIP fluxes in the Straits. Comparison of the seasonal chemical fluxes reveals that the DIN fluxes in the straits vary markedly with season, due to changes in both the DIN concentrations and volume fluxes. The winter DIN input from the Black Sea to the Marmara basin is about 4.64×10^8 moles, 20 times the autumn influx. A similar but less pronounced seasonality appears in the Marmara DIN input to the Aegean Sea via the Dardanelles.

Tab. 1. Seasonal & annual nitrate fluxes in the Bosphorus and Dardanelles straits.

| Flow type (layer) | Season | BOSPHORUS | | | DARDANELLES | | |
|-------------------|---------------|---|--|---|--|--|---|
| | | Volume (*10 ⁹ m ³) | NO ₃ conc. (mmol/m ³) | NO ₃ flux (*10 ⁸ moles) | Volume (10 ⁹ m ³) | NO ₃ conc. (mmol/m ³) | NO ₃ flux (*10 ⁸ mol) |
| Upper | Spring | 200 | 1,32 | 2,64 | 307 | 0,2 | 0,61 |
| Upper | summer | 158 | 0,42 | 0,66 | 194 | 0,12 | 0,23 |
| Upper | Autumn | 105 | 0,22 | 0,23 | 142 | 0,3 | 0,42 |
| Upper | Winter | 145 | 3,2 | 4,64 | 234 | 0,36 | 0,84 |
| Upper | Annual | 608 | 1,29 | 8,17 | 877 | 0,24 | 2,1 |
| Lower | Spring | 94 | 9,17 | 8,62 | 202 | 1,14 | 2,3 |
| Lower | summer | 76 | 10,46 | 7,95 | 112 | 0,47 | 0,52 |
| Lower | Autumn | 49 | 9,34 | 4,58 | 87 | 0,88 | 0,76 |
| Lower | Winter | 68 | 9,81 | 6,67 | 158 | 1,62 | 2,55 |
| Lower | Annual | 287 | 9,7 | 27,8 | 559 | 1,03 | 6,13 |

On an annual basis, the Black Sea inflow to the Marmara Sea is about four times greater than the DIN outflow to the Aegean basin via the Dardanelles, indicating that a large fraction of the DIN input from the Black Sea is converted to particulate and dissolved organic nitrogen compounds by photosynthetic activity in the Marmara Sea. DIN loads carried by the Bosphorus and Dardanelles undercurrents to the adjacent seas, however, display an opposite behavior. Indeed, on an annual basis, the Aegean DIN input (6.13×10^8 moles) to the Marmara lower layer is much less than the outflow (27.8×10^8 moles) to the Black Sea through the Bosphorus. In other words, the observed large stock in the Marmara deep basin is provided by particle snows (21.7×10^8 moles of nitrogen/year in the form of

labile PON) from the productive Marmara surface layer waters. Seasonal variations in the DIP fluxes via the exchange flows in the Straits are less pronounced than those estimated for DIN (Table 1). The Black Sea DIP input to the Marmara basin increases by nearly four times from autumn to winter (4.02×10^7 mol-P). A similar seasonal flow can be generated from the DIP input to the Aegean Sea via the Dardanelles Strait. On an annual basis, the Black Sea DIP input to the Marmara basin is comparable with the DIP outflow from the Marmara upper layer via the Dardanelles. On the other hand, the annual DIP outflow (27.9×10^7 mol-P) from the Marmara lower layer to the Black Sea via the Bosphorus is about 10-fold the input (2.57×10^7 mol-P/year) from the Aegean Sea.

Tab. 2. Seasonal & annual phosphate fluxes in the Bosphorus and Dardanelles straits.

| Flow type (layer) | Season | BOSPHORUS | | | DARDANELLES | | |
|-------------------|---------------|---|--|---|--|--|---|
| | | Volume (*10 ⁹ m ³) | PO ₄ conc. (mmol/m ³) | PO ₄ flux (*10 ⁶ moles) | Volume (10 ⁹ m ³) | PO ₄ conc. (mmol/m ³) | PO ₄ flux (*10 ⁶ mol) |
| Upper | Spring | 200 | 0,05 | 1,00 | 307 | 0,06 | 1,84 |
| Upper | summer | 158 | 0,03 | 0,47 | 194 | 0,03 | 0,58 |
| Upper | Autumn | 105 | 0,05 | 0,52 | 142 | 0,05 | 0,71 |
| Upper | Winter | 145 | 0,14 | 2,03 | 234 | 0,09 | 2,10 |
| Upper | Annual | 608 | 0,07 | 4,25 | 877 | 0,06 | 5,26 |
| Lower | Spring | 94 | 0,92 | 8,65 | 202 | 0,05 | 1,01 |
| Lower | summer | 76 | 0,99 | 7,52 | 112 | 0,03 | 0,34 |
| Lower | Autumn | 49 | 0,91 | 4,46 | 87 | 0,05 | 0,43 |
| Lower | Winter | 68 | 1,07 | 7,27 | 158 | 0,05 | 0,79 |
| Lower | Annual | 287 | 0,97 | 27,84 | 559 | 0,05 | 2,79 |

In conclusion, estimates of DIN and DIP exchange fluxes in the straits indicate that there is net DIN and DIP export from the Marmara to the Black Sea via the Bosphorus undercurrent. The Marmara upper layer acts as a sink for DIN input from the Black Sea and a large fraction of labile nutrients is accumulated in the lower stratum, with a nearly constant N/P ratio of about 8-10. Interestingly, the DIN input from the Aegean Sea to the Marmara basin exceeds the importation from the Marmara Sea via the Dardanelles Strait.

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