International Conference on Oceanography of the Eastern Mediterranean and Black Sea, similarities and differences of two interconnected basins, Athens (Greece), 23-26 February 1999. in, abstracts book, edited by E. Th. Balopoulos, A. Iona, D. Sakellariou, Athens, Greece, 1999.

NUTRIENT EXCHANGES BETWEEN THE BLACK SEA AND MEDITERRANEAN THROUGH THE MARMARA SEA

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ABSTRACT

Brackish waters of the Black Sea reach as far as the Aegean basin of the Mediterranean via the Bosphorus and Dardanelles straits and the intersectin basin, the Sea of Marmara, throughout the year. A counter flow in the two straits introduces the salty Mediterranean water to the Black Sea basin. The annual volume of the outflow from the Black Sea is nearly twice the salty water importation via the Bosphorus under current. Chemical properties of these exchange flows are modified in the elongated Marmara basin until the adjacent sea is reached. Organic carbon and phosphorus fluxes in the Bosphorus calculated by Deuser and Fonselius in the early 70's lower than the new estimates of IMS-METU group (Turkey) who used modern chemical data and new water fluxes. This difference originates principally from the underestimated old volume fluxes and long-term changes in the chemical properties of the Black and Marmara seas in recent decades. It is known that cyclonic alongshore currents in the Black Sea carry the contaminated surface waters of the northwestern shelf as far as the Bosphorus region, with some modification in their biochemical properties. The brackish Black Sea outflow through the Bosphorus, before reaching as far as the Dardanelles entrance, is further contaminated in the Marmara basin by land-based discharges and natural input from the lower layer of the Marmara Sea via vertical mixing of the counterflows in the Marmara Sea and Bosphorus Strait. During its transit over the Marmara basin labile nutrients are utilized in photosynthesis and thus partially exported out of the surface waters in form of particulate nutrients. Eventually, the brackish surface flow reach the Aegean basin of the Mediterranean with modified chemical properties. On the other hand, the salty Mediterranean waters flow into the Marmara deep basin with originally low nutrient concentrations. During its 6-7 years sojourn in the Marmara basin, the salty waters become very poor in dissolved oxygen (30-50 uM) with concomitant increases in the dissolved inorganic nutrient concentrations, due to particle snows from the brackish waters occupying the Marmara surface layer.

Until late 80's, the physical and chemical oceanography of the two-layer flow regimes in the Turkish straits, Dardanelles and Bosphorus, have been poorly understood due to the scarcity of systematic data. Recent studies have addressed the critical role of the Black Sea input for the Marmara ecosystem. In this report, based on the well defined boundaries of the counter-flows at both the exits of the straits and using long-term hydrograhic and chemical data obtained by the scientists of Marine Sciences Institute (Turkey) since 1986, we have examined the nutrients contents of the Black Sea and the Mediterranean waters exchanged via the Turkish straits. In addition, we have estimated the annual nutrients loads exchanged between the adjacent seas, using new volume fluxes.

Nutrient Content of the Black Sea water in the Turkish Straits: Depth-averaged nitrate and phosphate concentrations of the brakish surface flow in the Bosphorus are very low (NO_3=0.05-0.2 μM; PO_4=0.02-0.1 μM) in the summer-autumn period , then increasing to peak values of 4.5-7 μM for NO_3 and 0.2-0.4 μM for PO_4 in early winter months. A similar seasonal trend was also observed in the salty Mediterranean inflow to the Marmara basin via the Dardanelles Strait. Such drastic winter increases are principally the result of not only apparent decline in their photosynthetic uptake rates and also thoroughly vertical mixing of the nutrient rich lower layer waters of the northwestern Black Sea shelf region. These coastal waters also receives large loads of nutrients by riverine and direct waste discharges, before flowing towards the Bosphorus region. Particulate nutrients (PON, PP) in the Bosphorus surface flow always increases markedly during the early spring bloom, with concomitant decreases in the nitrate and phosphate concentrations. Although different forms of nutrients exhibit large seasonal variation in the Black Sea outflow via the Bosphorus the annual averages of biochemically labile nitrogen and phosphorus compounds calculated from long-term data are comparable but particulate nutrients being relatively high (NO_3=1.3 μM; PON: 1.8 μM; PO_4=0.11 μM; PP=0.21 However, the annual averages of dissolved organic phosphorus (DOP=0.30 μM) and nitrogen (DON=18.0 μM estimated for the Bosphorus surface flow constitute nearly 50 and 80% of the mean TP (0.56 μM)and TN (21.7 μM , respectively. Since DON and NH4 have not measured in the Turkish straits their averages have been derived from limited data in the literature and using DOC/DON ratios in the seas.

The biochemical properties of the Black Sea outflow in the Marmara upper layer are partly modified by various factors until the Dardanelles Strait is reached. The natural source is the input from the Marmara lower layer by intense vertical mixing of the counter-flows especially in the Bosphorus-Marmara junction region. Waste water discharges originates

principally from the city of Instanbul. Photosynthetic uptake of labile nutrients in the surface layer leads to a net export of particulate nutrients from the surface layer to the deeper waters. These counteracting processes result in a net decrease in the total nutrient contents of the brackish surface flow (TP: 0.56 to 0.44 μM and TN 21.7 to 15.4 μM). Moreover, apparent changes occurs in the relative importance of different forms of nutrients in their totals until the brackish waters reach as far as the Dardanelles entrance in some months; the nitrate mean drops to 0.33 μM, in addition to the winter nitrate peak values observed in the Bosphorus surface flow becomes much less pronounced in the Dardanelles Strait.

Nutrient Content of the Mediterranean flow in the Turkish Straits: The salty Mediterranean waters flow into the Marmara basin with seasonally varying nutrient concentrations (NO_3=0.1-2.4 μM; PON=0.04-0.7 μM; PO_4=0.02-0.08 μM; PP=0.01-0.35 μM), their levels being very low for most the year. In winter NO_3 and PO_4 values reach maximal levels, exceeding the concentrations of the brackish waters (of Black Sea origin) flowing from the Marmara upper layer to the Aegean basin throughout the year. The estimated annual means of the nitrogen and phosphorus compounds are as follows: NO_3=1.0 μM; PON=0.3 μM; PO_4=0.05 μM; PP=0.02 μM; DOP=0.05 μM. The annual averages of NH_4 (0.1 μM) and DON (3.0 μM) have been obtained from limited data in the literature. The annual means estimated for the Mediterranean inflow to the Marmara basin are 4.4 for TN and 0.12 μM for TP, which are about three times less than those for the brackish waters (Black Sea origin) flowing into the Aegean Sea via Dardanelles Strait.

The nutrient content of the salty Mediterranean water is modified markedly in the Marmara. During its 6-7 years sojourn in the Marmara basin the salty flow becomes enriched nearly 10-fold with dissolved inorganic nutrients (PO_4= 0.7-1.3 μM and NO_3=7-12 μM), by the input from the Marmara surface waters in the form of particulate nutrients, before the Bosphorus-Marmara junction region is reached. Therefore the salty water in the Bosphorus is much rich in NO_3 and PO_4 but poor in particulate nutrients (PON=0.2-1.0 μM; PP= 0.03-0.07 μM) because primary production is always limited to the upper layer of the Marmara Sea.

Estimates of Nutrient Fluxes via the Dardanelles and Bosphorus Straits: Based on the annual means of various forms of nutrient concentrations estimated for the exchange flows and using the new volume fluxes in the Bosphorus and Dardanelles straits, we have calculated the annual loads of TP and TN exchanged between the Mediterranean and Black Sea via the two straits. We should note that the upper layer volume flux (804 km^3/year) in the Dardanelles is nearly 50% larger than that (562 km^3/year) in the Bosphorus due to the entrainment of salty Mediterranean water into the brakish waters of Black Sea origin, occupying the Marmara upper layer. The salty Mediterranean inflow introduces nearly $0.19x10^4$ tonnes of TP and $0.31x10^5$ of TN per year into the Sea of Marmara via the Dardanelles. Nearly 50% of the salty water inflow (504 km^3/year) to the Marmara basins, enriched markedly with dissolved inorganic nutrients during its 6-7 years sojourn in the basin, is returned back to the Aegean Sea by the Marmara surface flow towards the Dardanelles Strait as a result of the vertical mixing of the counter-flows in the Marmara basin. Thus the remaining ((263 km^3/year) of the salty inflow reaches the Black Sea intermediate depths with an apparently increased nutrient load - annually $0.9x10^4$ tonnes of TP and $0.5x10^5$ tonnes of TN. A counterflow in the Bosphorus introduces annually $0.98x10^4$ tonnes of TP and $1.7x10^5$ tonnes of TN from the Black Sea to the Marmara upper layer. Almost similar TP and TN loads reach the Aegean Sea via the Dardanelles surface currents.

In conclusion, the TP export from the Black Sea via the Bosphorus surface flow is almost compensated by the influx from the Marmara Sea. A similar conclusion may be reached for the exchange fluxes of biochemically more labile nitrogen species in the Bosphorus due to large nutrient input to the Mediterranean water in the Marmara basin from the Marmara surface waters. The two-layer ecosystem of the Marmara Sea acts as a sink for biologically labile nutrients of Black Sea origin, from atmospheric input and land-based (domestic + industrial) discharges. The nutrient input from the Marmara upper layer to the Aegean basin of the Mediterranean Sea are at least 4-5 times the annual outfluxes from the Aegean Sea via the Dardanelles undercurrent, indicating a net mass transfer from the Black Sea to the Mediterranean via the Turkish Strait System. The nutrient input from the Black Sea to Aegean Sea via the Marmara basin is much lower than the Atlantic inflow the Mediterranean but is expected to have an important contribution to nutrient balances in the Aegean basin of the northeastern Mediterranean.