UNDERSTANDING WHY NUTRIENT CYCLING IN THE EASTERN MEDITERRANEAN (EMS) IS SO UNUSUAL?

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Abstract

The high N:P in the EMS is due to high N:P ratio in the external inputs combined with low denitrification caused by its ultra - oligotrophic status. There is no evidence for N-fixation. The external inputs have increased by 2-5 times between 1960 and 2000 and yet there is no evidence of increased primary productivity. We suggest this is due to rapid export of excess nutrients through the Straits of Sicily.

Keywords: Eastern Mediterranean, Phosphorus, Pollution, Geochemical Cycles

The EMS is both P starved and unequivocally phosphorus limited with a nitrate:phosphate ratio in the deep waters of ~28:1 and similar high ratios in the dissolved and particulate organic matter (1). It is also unusual in being ultra-oligotrophic. This is despite the basin being surrounded by land with a resident population of ~ 120 million people and a further 120-200 million tourists yearly. As a result of this large population there are considerable external inputs of nutrients (N & P) from both atmospheric and riverine sources. Recent studies have shown that the high N:P ratio found in the EMS is due to a combination of high N:P ratios in the external inputs combined with low denitrification rates. This is because there are limited areas of anaerobic sediment due the ultra-oligotrophic nature of the basin. A total nutrient budget for the entire basin shows that the external inputs balance closely the outputs (Table 1) without any nitrogen fixation.

Tab. 1. Calculated nutrient inputs into and outputs from the Eastern Mediterranean basin. All values as given in 10^9 moles/y. The data for the total nutrient budget is from Krom et al., (2004) with subsequent data from Ludwig et al., (2009)

Source	N input/	P input/	Molar N:P
Atmospheric input (1996-1999)	111	0.95	117
Riverine input	63	2.4	26.3
Black sea	8	0	-
Total inputs to basin	**180**	**3.4**	**54**
Straits of Sicily	142	4.4	32
Sediment deposition	27	1.0	27
Sediment denitrification	10	-	-
Total output from basin	**179**	**5.4**	**33**
Atmospheric input (1960)	50.5	-	
Atmospheric input (1996-1999)	111	0.95	117
Riverine input (1963)	10.8	0.51	21.2
Riverine input (1998)	51.0	1.04	49.2

A similar budget for the core of the Cyprus eddy found that the annual inputs of fixed nitrogen into the core of the eddy balanced by known exports (2). Both budgets were in balance without any significant nitrogen fixation. Previous explanations for the observed isotopically light δ^{15}N-NO_3 (2.4± 0.1‰) in the deep water which suggested extensive nitrogen fixation did not take into account the isotopic signature of the atmospheric input. Recent measurements have shown that this external input is isotopically light (δ^{15}N = -3.1‰) and together with the known atmospheric N flux is able to explain the isotopic content of nitrate in the deep water without any nitrogen fixation (5) Direct measurements of nitrogen fixation across the EMS have found rates at or below detection limits; (0.5-2 µmol/m^2/d; and ~1 nmol/l/d;. The exceptionally high nitrogen fixation rates in the Cyprus eddy (3) (129 nmol/l/d; 15 mmol/m^2/d) are considered anomalous particularly since the only potential diazotroph observed within the system at the time of measurement were *Synechococcus sp*. and these were found in low numbers (3.3-4.3 x 10^6 cells/l;. This explanation for the unusual N:P ratio in the EMS is entirely compatible with existing explanations for the global controls of the Redfield ratio as being a balance between denitrification removing N to below 16:1 and subsequent N fixation adding fixed nitrogen. The EMS is simply unusual because there is almost no denitrification, even in the coastal sediments.

The low nutrient concentrations in the deeper water in the EMS, which is the cause of the observed ultra-oligotrophic conditions, is due to the anti-estuarine circulation with low nutrients being supplied by the in-flowing surface waters and significant nutrient export in the outflowing intermediate water. The external flux of fixed nitrogen in the atmospheric supply has increased by a factor of 2.2 since 1960 while the riverine flux has increased by a factor of 4.5 during the same time period (Table 1). The riverine P flux has also increased by a factor of ~2 (4). Despite these major increases in external nutrient flux, there is no evidence of a parallel increase in primary productivity or any other regional measure of eutrophication. We propose that this is because the nutrients are exported with the outflow at the Straits of Sicily with nutrients having a residence time of only <10 years in the EMS. These new understandings have important implications on our understanding of biogeochemical cycles within the EMS basin and need to be taken into account in any attempts to predict the effect of changing nutrient fluxes or ocean acidification on this sensitive ecosystem.

References

1 - Krom, M.D., Herut, B., Mantoura, R.F.C., 2004. Nutrient budget for the eastern Mediterranean: Implications for P limitation. *Limnol. Oceanogr.*, 49: 1582-1592.

2 - Krom, M.D., et al ., 2005. Nutrient cycling in the south east Levantine basin of the Eastern Mediterranean: results from a phosphorus starved system. *Deep-Sea Res. II,* 52: Nos 22-23 2879-2896.

3 - Rees, A.P., Law, C.S., Woodward, E.M.S., 2006. High rates of nitrogen fixation during an in-situ release experiment in the Eastern Mediterranean sea. *Geophys. Res. Letters*, 33: L10607.

4 - Ludwig, W., Dumont, E., Meybeck, M., Heussner, S., 2009. River discharges of water and nutrients to the Mediterranean and Black Sea: Major drivers of ecosystem changes during past and future decades? *Progress in Oceanography* 80: 199-217.

5 - Mara. P., Mihalopoulos, N., Gogou, A., Daehnke, K., Schlarbaum, T., Emeis, K.-C., Krom, M.D., 2009. Isotopic composition of nitrate in wet and dry atmospheric deposition on Crete/ Eastern Mediterranean Sea. Global Biogeochemical Cycles.