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ATMOSPHERIC INPUTS OF NITROGEN AND PHOSPORUS TO THE SOUTH EAST MEDITERRANEAN: THE ROLE OF DESERT/SAHARA DUST EVENT AS N AND P SUPPLIER

UNEP/MAP
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Preface

Monitoring and assessment of airborne pollution was included within the framework of MED POL Phase III, basically under monitoring (and assessment) of diffuse sources of pollution. In MED POL Phase III, a number of regional assessments and evaluations were published by UNEP/MAP in close cooperation with World Meteorological Organization (WMO). MAP Technical Reports Series Nos 118 (1997), 122 (1998), 130 (2001) and 133 (2001) were the major publications.

In terms of monitoring activities organized within the above context, IOLR (Israel) was the only data source for the MED POL Database during the official period of Phase III. The results on the atmospheric deposition of trace metals and nutrients provided to MED POL were thoroughly evaluated for the South East Mediterranean and published in the scientific journals and reports. This report presents a summary of some of those publications both on trace metals and nutrients, and particularly deals with the atmospheric dry fallout of nitrogen and phosphorus to the surface waters of the Levantine basin as a source of nutrients and their possible impact on primary production of the surface waters of the specified region.

The role of desert/Sahara dust event as N and P supplier to the SE Mediterranean

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[1] This report summarizes research performed with several colleagues: Mike Krom, Patricia Carbo, Nilgun Kubilay, Malcolm Nimo, Mustafa Kocak and others.

Executive Summary

This report summarizes a two phase project aiming to assess the role of atmospheric dry fallout as a source of new nitrogen and phosphorus to the surface Levantine seawater, and its potential impact on new productivity, especially during dust ‘pulse’ events. This enabled us to develop a clearer understanding of the magnitude of atmospheric dry fallout as a source of new nitrogen and phosphorus to the Levantine basin, and its importance as compared to atmospheric wet deposition and to fluvial sources. Thus, the main questions that motivated the projects were:
Do aerosols and dust particles in particular, play an important role in: a) long-term supply of nutrients (fertilization)? b) short-term supply of nutrients by dust storm events or in phytoplankton blooms production or in grazing? c) affecting NO_3^-:PO_4^{3-} ratios in deep water?

The project was focused on the dry deposition component because estimates of wet deposition fluxes of inorganic nutrients (PO_4^{3-}, NO_3^-, NO_2^-, NH_4^+) at sites along the Mediterranean coast of Israel are made as part of a long term study (MEDPOL Phase II and III monitoring activities, Herut et al., 1999, 2005). The collected individual rainwater events represent 70-80% of the total annual precipitation.

In the first phase of the project, leaching experiments of inorganic nitrogen ($LINO_3$, $LINH_4$) and phosphorus ($LIPO_4$), using SE Mediterranean surface seawater, were performed on 41 aerosol ('dust') samples collected on Whatman 41 filters between April 1996 and January 1999 at Tel Shikmona, Israel and on 4 desert-event dust powder samples. During phase two an additional 71 analyses were performed on samples collected between January 2001 and April 2003, and on board RV Aegaeo during the CYCLOPS cruises in May 2001 and May 2002. Sampling time was usually about 70 hours per filter with an average frequency of 11 days per month (~30% time coverage).

The table hereafter summarizes the estimated average wet, dry and leachable (soluble) inorganic N and P atmospheric fluxes over the SE Mediterranean based on the above long-term measurements. It is reasonable to suggest that the dissolved (wet) plus seawater leachable fluxes represent the amount of nutrient which is bioavailable in the surface waters. This assumes that there is no significant adsorption onto or desorption from inorganic particles after they reach the surface waters.

Nutrient mmol m^{-2} yr^{-1}	**Dry**	**Wet**	**Bioavailable**
N	50	20	~70
P	1	0.3	~0.7

It is evident; however, that the Levantine Basin is exposed to significant temporal and spatial variability of wet and dry depositions, which should be further assessed by both, ground measurements and numerical models. For example, significant inter-annual variations in wet inorganic N and P fluxes were recorded at the Israeli Mediterranean coast (Haifa), probably attributed to changes in the annual precipitation and nutrient emission intensities (**Fig. 1**). To serve as an example of the typical temporal variability in the dust concentrations the variability of the Al aerosol concentrations during a three year period (1999-2001) at two coastal sites located at the northern, Erdemli (Turkey) and southeastern, Tel Shikmona (Haifa, Israel), region of the Levantine Basin are shown in **Fig. 2.** There is a general increasing gradient of the crustal material load from south to north across the Levantine Basin, especially during Saharan dust events, with enhanced concentrations of Al (1.7) observed at Haifa compared to Erdemli during common dust events (**Fig. 3**). Nevertheless, in several simultaneous sampling dates similar levels of Al concentration in air were recorded (**Fig. 4**).

The main question addressed in the first phase of the project, and further dealt with in the second phase was do aerosols play an important role in the long-term supply of nutrients? A comparison of the atmospheric bioavailable flux of P to the net P outflux from Sicily Straits emphasize the significant contribution from the atmosphere (**Fig. 5**). It was estimated that this atmospheric contribution of new nutrients to the basin supports 15-70% of its new production (Herut et al., 2002, 2004). In addition, it was estimated that the atmospheric insoluble flux of phosphorous is similar to the burial rates of phosphorous in sediments and hence a dominant source of the sedimentary phosphorous pool in this basin (**Fig. 6**).
During the second phase a multi-source mass balance of phosphorous and nitrogen was performed by Krom et al. (2004) as detailed in the table below. While the nitrogen budget was balanced the phosphorous was not because of unknown reasons.

Best estimates for the nutrient fluxes into the East Mediterranean (Krom et al., 2004) (in 10^9 mol yr^{-1})			
Source:	**N input**	**P input**	**Molar N:P ratio**
Atmospheric input	111	0.95	117
Riverine input (Po and adjacent area of N.Adriatic)	20	0.9	22
Nile input	15	0.25	60
Riverine input from rest of basin	28	1.25	23
Black Sea	8	0	-
Total input to basin	180	3.4	54
Best estimates for nutrient fluxes out from the basin			
Straits of Sicily	142	4.4	32
Sediment deposition	27	1.0	27
Sediment denitrification	10		n.a.
Total output from basin	179	5.4	33

The main questions addressed in the second phase were: a) how leachability is dependent on the aerosol source and b) does a single dust storm have a fast impact?

Several measurements showed that the leachability is dependent on aerosol sources as follow:
Release of IN: Dust events << European aerosols
IP solubility: Dust events << European aerosols
Leachable N/P: Dust events << European aerosols
Leachable inorganic nitrogen concentrations and fluxes are higher in background (non dust storm) samples than in dust storm samples, probably due to the smaller grain size and aerosol source (**Fig. 7**). Total P is supplied naturally with the dust, as shown by the close correlation between total P and Al (r^2 = 0.95) (**Fig. 8**). However, there is a poor correlation between leachable inorganic P (LIP) and Al (r^2 = 0.20, **Fig. 8**), which may be related to grain size effects and/or recycling processes in the atmosphere. Even so, the supply of LIP to surface waters is greatest during dust storms due to the comparatively high deposition of aerosol material.
The ratios of seawater LIN/LIP decreases exponentially with increased rock/soil component (e.g. Al) from values close to 400:1 (**Fig. 9**). Even during dust events where the N:P ratio is at its lowest, the ratio is still well above Redfield ratio (N:P = 16:1).

The possible contribution of the atmospheric inputs to the relatively high N:P ratios in the Levantine deep water was emphasized by the results obtained during the two phases of the project. Nevertheless, the cause of this anomaly is still unknown and several hypotheses were suggested to explain this unusually high NO_3^-:PO_4^{3-} ratios in E. Mediterranean deep water:
1) Nitrogen fixation (Bethoux et al., 1998, new evidence from ^{15}N).
2) Inorganic removal of phosphate on to particulate matter, particularly in the deep water column (Krom et al., 1991), shown later to be insignificant (Herut et al., 1999a; Carbo et al., 2005).
3) Contribution of atmospheric precipitates with relatively high NO_3^-:PO_4^{3-} ratios (~80) (Herut et al., 1999b; 2002; Carbo et al., 2005).
4) Formation of NO_3^- enriched deep eastern Mediterranean waters of Adriatic origin (Civitarese et al., 1998),
5) All input sources to the basin have N/P>>16 as detailed in the above nutrient budget, which is retained because of insignificant denitrification (Krom et al., 2004).

To assess whether a single dust storm has a fast impact, an on-board microcosm experiment was performed during the CYCLOPS May 2002 cruise, to track the biogeochemical response of Eastern Mediterranean surface seawater to a gradient addition of fresh and pre-leached Saharan dust, mimicking the potential fertilization effect as opposed to the impact of adding particles alone (Herut et al., 2005). Response parameters examined were P turnover time, bacterial production and abundance, chlorophyll a, other phytopigments, abundance of different pico and nanophytoplankton groups, primary production rates, abundance of heterotrophic nanoflagellates and ciliates. The addition of fresh Saharan dust (range: 0.2 to 4.9 mg l^{-1}) and the subsequent nutrient release triggered an increase in phytopigments and primary production, while no response was detected for pre-leached dust particles. Most responses were linearly related to the amount of fresh dust added

A less clear response was recorded by *in-situ* measurements following a Saharan dust storm during a cruise in the Levantine Basin in May 2001 (**Fig. 10**). The calculated amount of nutrients and dust particles delivered by such an event to a 15 m thick mixed surface layer is low (~0.3 nmole P l^{-1}, ~9 nmole N l^{-1} and 0.06 mg dust l^{-1}), falling close to the lowest dust addition in our microcosm experiment. Even so, an enhancement of phosphate turnover time, a sharp decline of *Prochlorococcus* abundance, and slight increases in chlorophyll a and bacterial activity were observed in response to the dust storm. Considering the linear effect of fresh dust concentrations on the bacterial activity, primary production and pigment concentration (total and per cell), and the likely stimulation of grazing, it is not surprising that changes due to moderate strength dust storms are mostly close to detection limit of either field or remote sensing measurements.

To better understand the impact of dust and the input of atmospheric nutrients into this basin further regional study is needed. We still remain with several basic open questions such as:

How recycling reactions in the atmosphere, prior to its contact with surface seawater, effect dust reactivity? and what is the effect of longer residence time in the atmosphere?

What is the effect of particle size?

Why is Saharan dust in the eastern Mediterranean so unreactive towards adsorption of phosphate?

Why Western and Eastern dust samples show differences in P adsorption capacity?

How P is mobilized from dust to gut?

Does dust cause phytoplankton blooms or are they grazed away immediately by the ‘hungry starved lions’

Does dust cause N fixation or not?

Publications in which MED POL Phase III is acknowledged (see abstracts in Appendix)

Phase I

Herut B., Collier R. and Krom M.D. (2002). The role of dust in supplying N and P to the SE Mediterranean. *Limnol. Oceanog.* 47: 870-878.

Herut B. (2004). Atmospheric input of inorganic N and P to the SE Mediterranean, comments on total and bioavailability assessment. In: A. Yilmaz (ed.), Oceanography of the Eastern Mediterranean and Black Sea, Tubitak Publishers, Ankara, Turkey, pp 229-235.
Following the Second International Conference on the “Oceanography of the Eastern Mediterranean and Black Sea: Similarities and Differences of Two Interconnected Basins. Ankara, Turkey (14-18 October, 2002).

Phase II

Herut, B., Krom, M., Carbo, P. and Nishri, A. (2003). Atmospheric input of nutrients, impact on East Mediterranean waters. 2nd Workshop on Mineral Dust, Paris, 10-12 Septembre 2003.

Herut, B., Kocak, M., Nimmo, M. and Kubilay, N. (2003). Spatial trends of aerosol trace metal concentrations in the Levantine Basin of the Eastern Mediterranean. 2nd Workshop on Mineral Dust, Paris, 10-12 Septembre 2003.

Herut, B., Krom, M. and Carbo, P. (2004). Atmospheric input of nutrients, impact on East Mediterranean waters. *Rapp. Comm. Int. Mer. Medit*. 207.

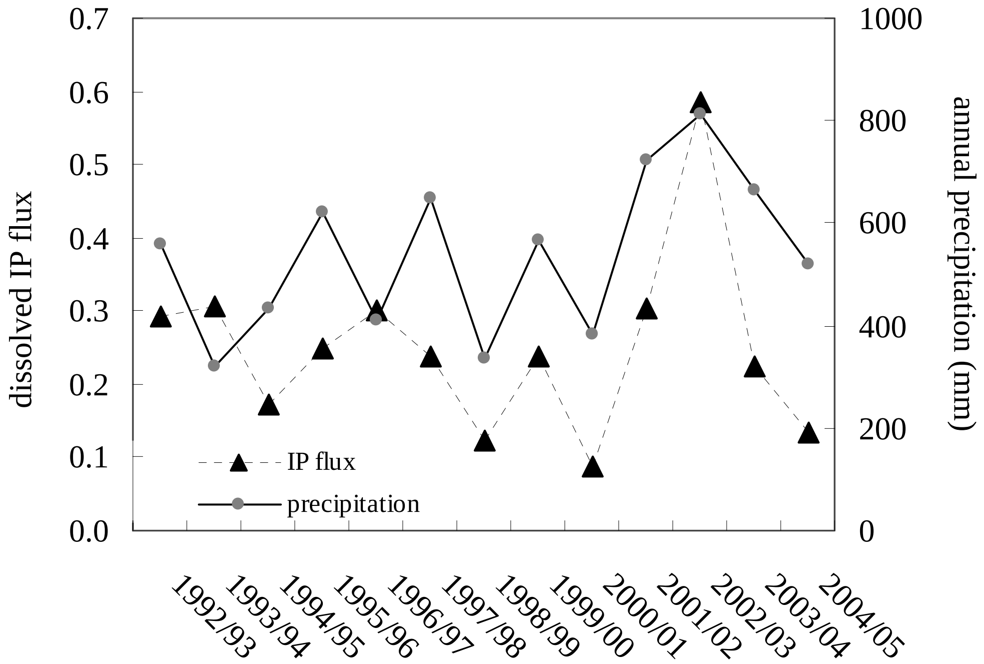
Kocak M., Nimmo M., Kubilay N. and **Herut B.** (2004). Spatio-temporal aerosol trace metal concentrations and sources in the Levantine Basin of the Eastern Mediterranean. *Atmos. Environ.* 38: 2133-2144.

Krom M.D, **Herut B.** and Mantoura F. (2004). Nutrient budget for the Eastern Mediterranean: Implications for P limitation. *Limnol. Oceanog.* 49: 1582-1592.

Koçak M., Kubilay N., **Herut B.** and Nimmo M. (2005). Dry atmospheric fluxes of trace metals (Al, Fe, Mn, Pb, Cd, Zn, Cu) over the Levantine Basin; A refined assessment. *Atmos. Environ.* 39: 7330-7341.

Carbo P., Krom, M.D., Homoky W.B., Benning L.G., **Herut B.***, (2005). Impact of atmospheric deposition on N and P geochemistry in the southeastern Levantine basin. *Deep-Sea Research*
*** corresponding author**

Herut, B. , Krom, M.D. , Law, C., Mantoura, R.F.C., Pitta, P., Psarra, S., Rasssoulzadegan, F., Rees, A., Thingsted, F., Tanaka, T., Zohary, T (2005). Response of East Mediterranean surface water to Saharan dust: on-board microcosm experiment and field observations**.** *Deep Sea Research.*



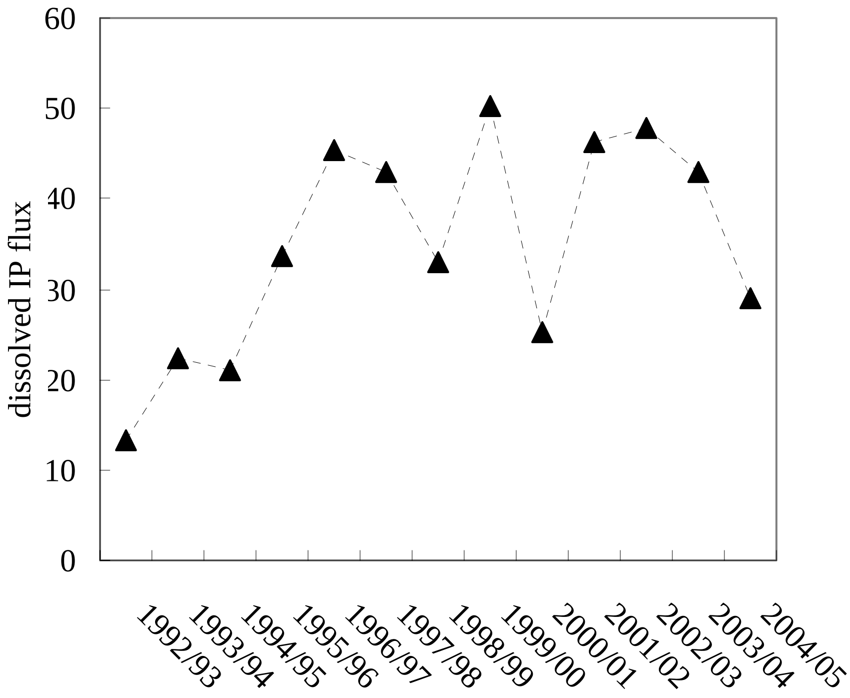


Fig. 1: Atmospheric wet fluxes of inorganic phosphorus (IP) and inorganic nitrogen (IN) (mmol m^{-2} yr^{-1}) at Tel-Shikmona during 1992 – 2004. The annual amount of precipitation at Haifa port is included. (Herut et al., 2005)[2]

[2] **Herut, B.**, Shefer, E., and Cohen, Y. (2005). Quality of the coastal Mediterranean marine environment in Israel during 2003. IOLR Rep. H34/2005, (in Hebrew). IOLR Rep. H34a/2005 – Executive summary in English.

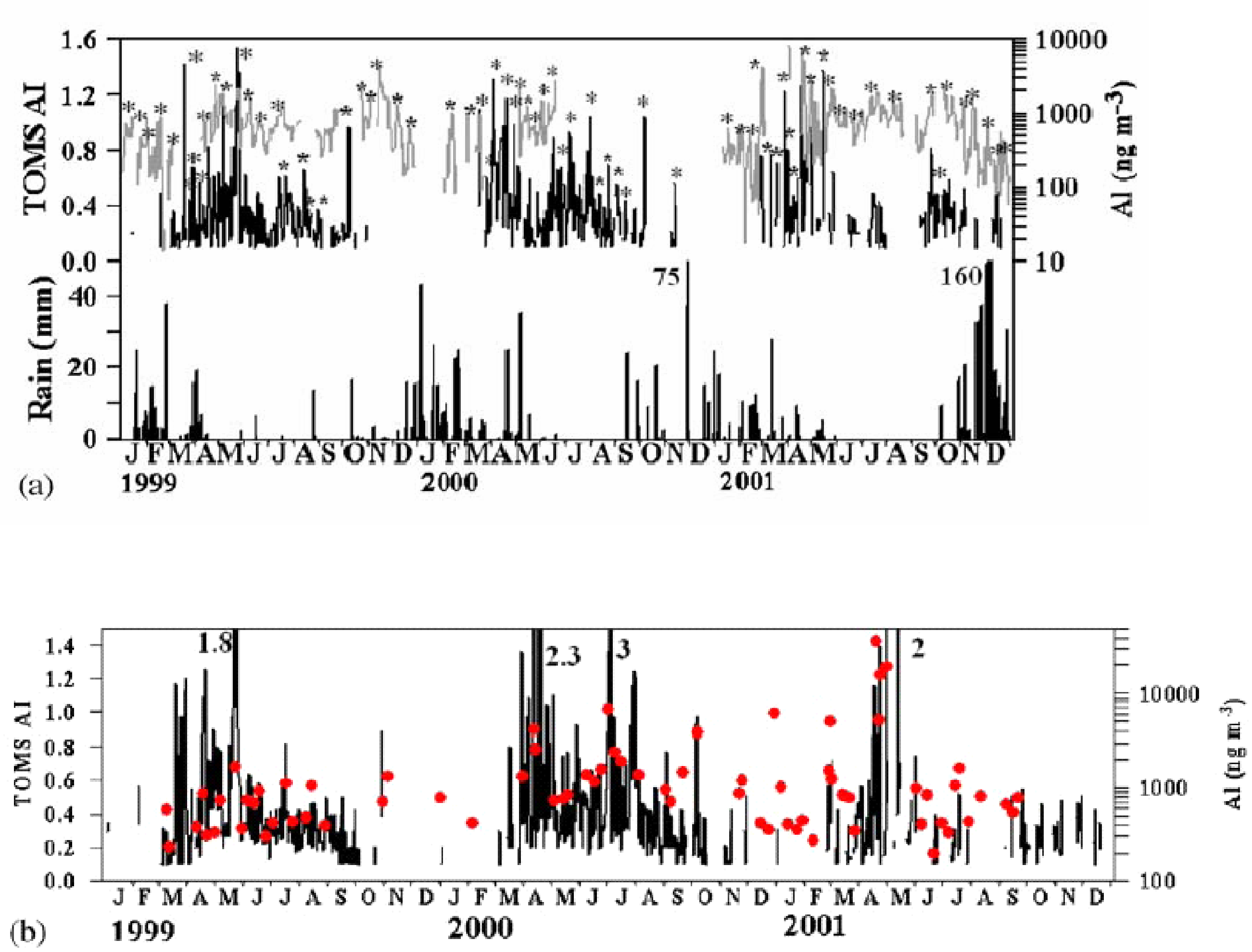


Fig. 2: Time series of: (a) daily aerosol Al concentrations (gray line) and TOMS aerosol index (black line) at Erdemli (Turkey). Daily local precipitation rate is indicated at the bottom; (b) three day integrated aerosol Al concentrations (dots) and TOMS aerosol index (black line) at Tel-Shikmona (Haifa, Israel). (Kocak et al., 2004).

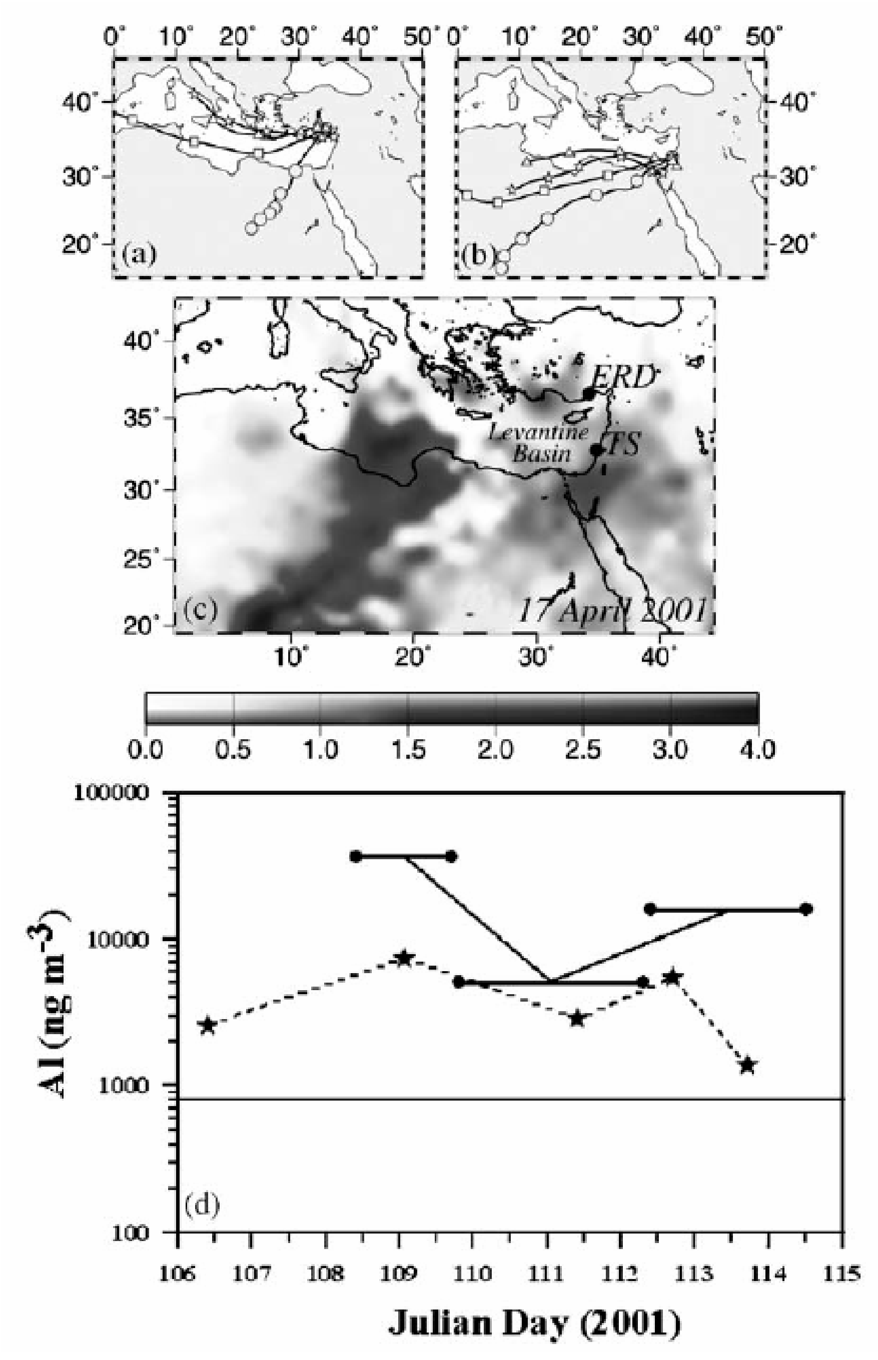


Fig. 3: Three day back trajectories illustrating the transport of air masses on the 18th April 2001 to Erdemli (a) and TS (b). The back trajectory pathway every 12 hours is indicated by triangles for 1000 hPa, stars for 850 hPa, circles for 700 hPa and squares for 500 hPa. Regional aerosol index distribution is highlighted in (c) and on (d) the time series of aerosol Al concentrations at TS (unbroken line) and Erdemli (dashed line) during 16-24 April 2001 (Julian day 107-115) are presented. Geometric mean of aerosol Al concentration (813 ng m^{-3}) in the transitional season at Erdemli is indicated on the diagram as a continuous line. (Kocak et al., 2004).

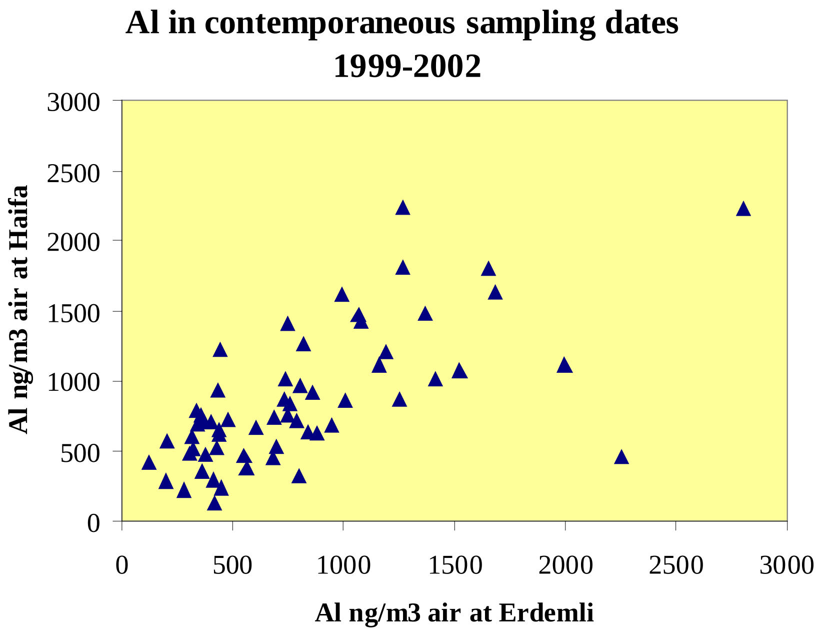


Fig. 4: Aerosol Al concentrations at Tel-Shikmona (Haifa, Israel) and Erdemli (Turkey) during contemporaneous sampling dates.

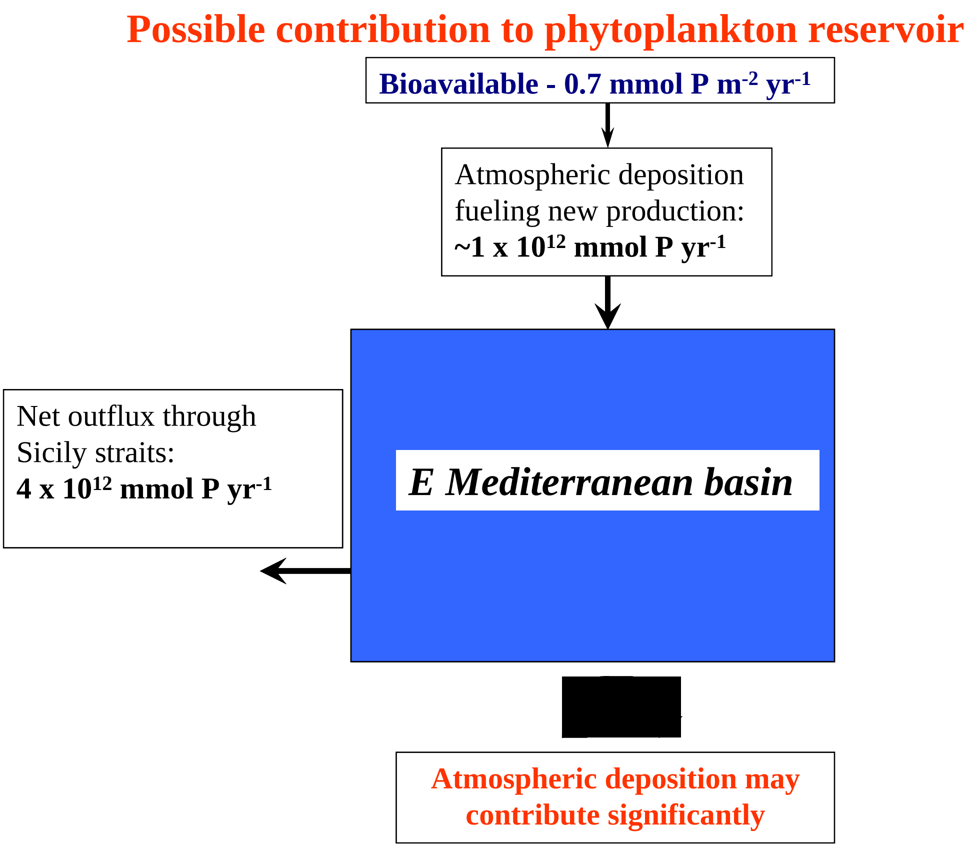


Fig. 5: Estimated contribution of atmospheric bioavailable phosphorous to the E Mediterranean basin.

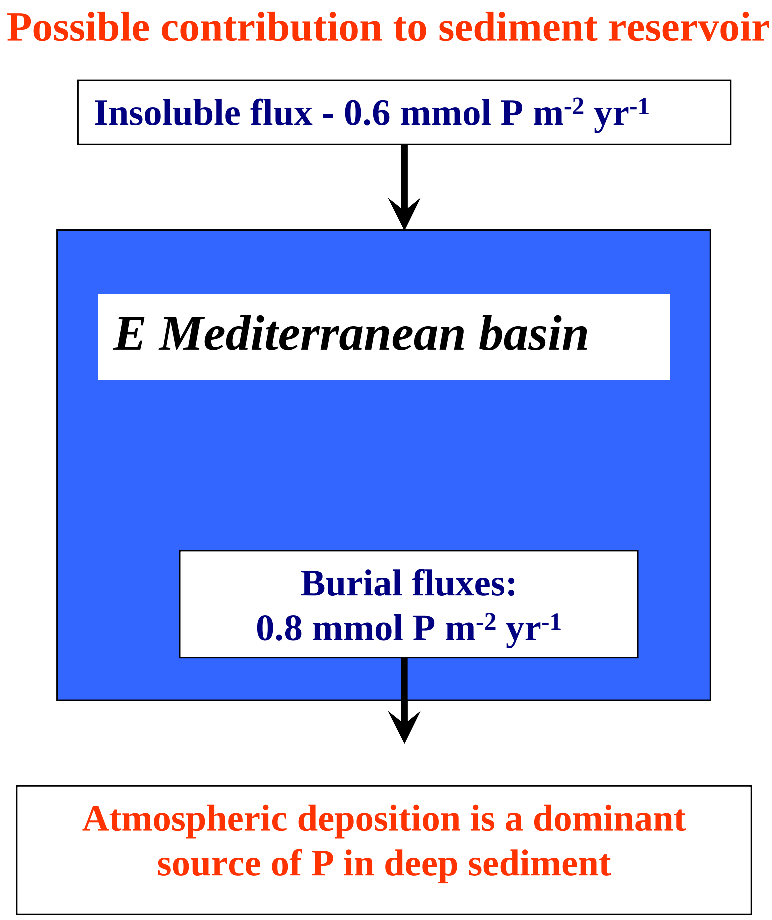


Fig. 6: Estimated atmospheric insoluble phosphorous fluxes and burial rates in the E. Mediterranean basin.

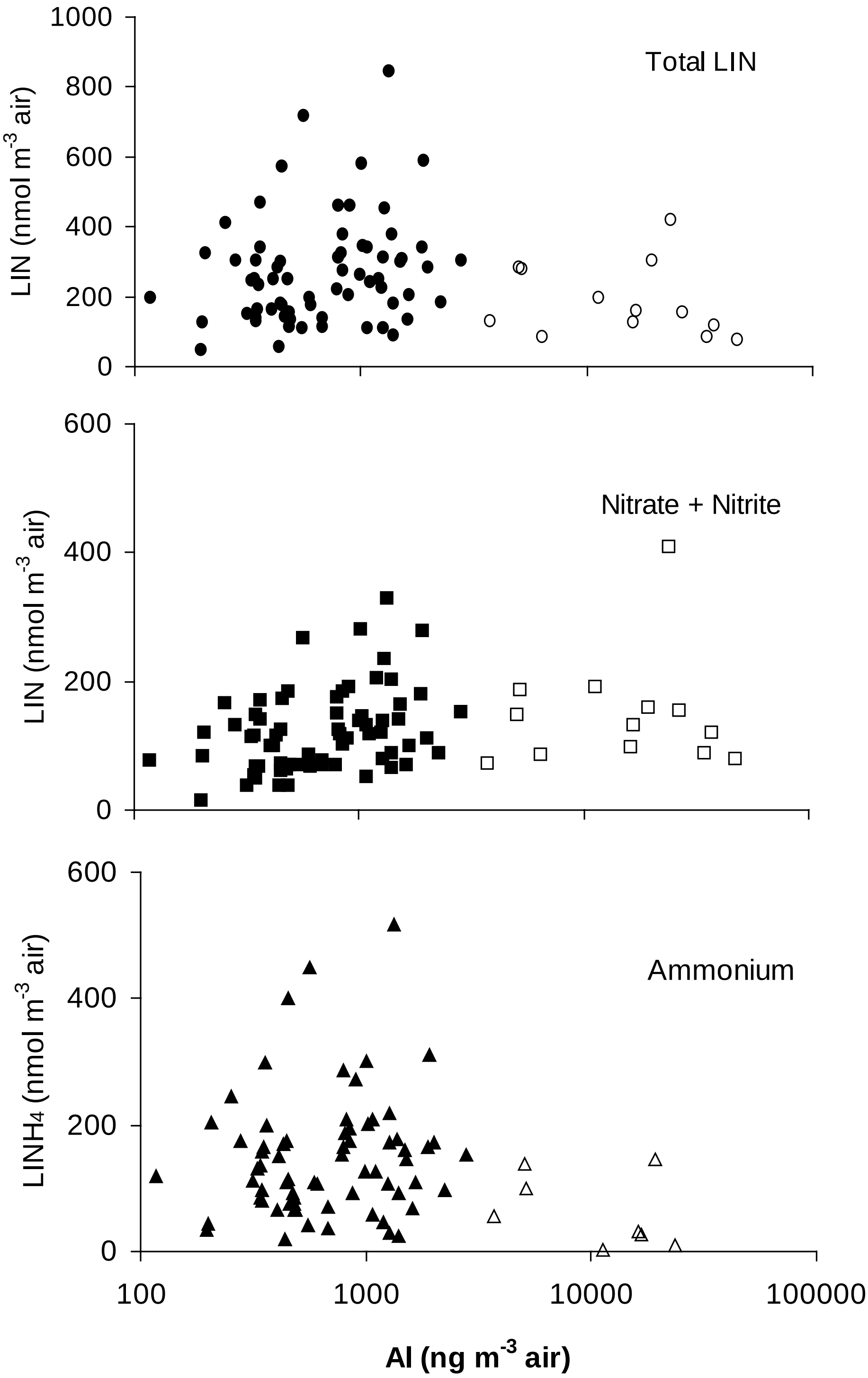


Fig. 7: The relationship between dust-borne leachable nitrogen and dust load (Al concentration) in air. Empty symbols – dust storm samples, full symbols – background samples. LIN- leachable inorganic nitrogen. (Carbo et al., 2005)

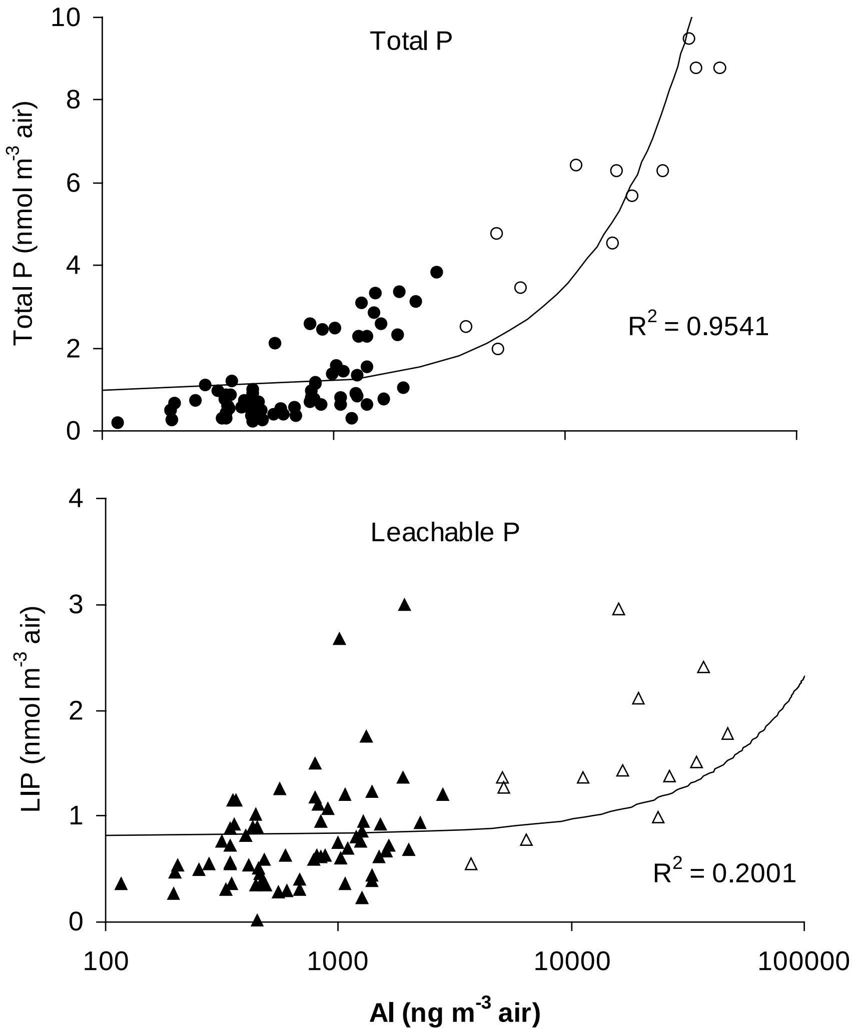


Fig. 8: The relationship between dust-borne phosphorus and dust load (Al concentration) in air. Empty symbols - storm samples, full symbols – background samples.LIP- leachable inorganic phosphorus. (Carbo et al., 2005)

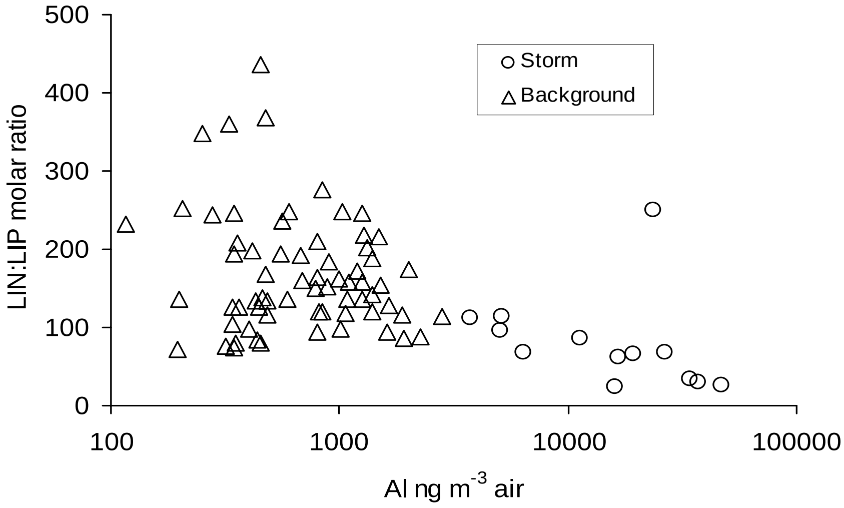


Fig. 9: LIN:LIP molar ratios calculated from fluxes, and plotted against Al concentration (representing dust load) in air. (Carbo et al., 2005)

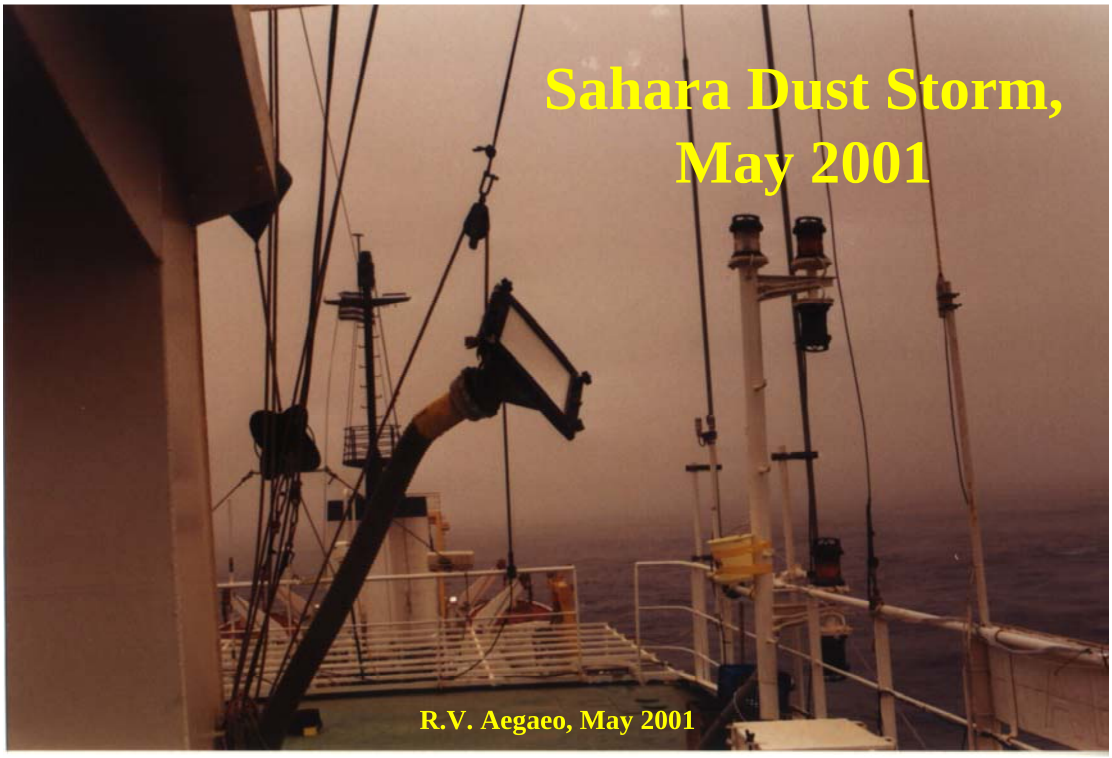


Fig. 10: Murky skies photographed during a dust storm (upper panel) that began the night between 12 and 13 May 2001, and lasted till about 11:00 h of 13 May, and the clear sky a few days earlier (lower panel). During the height of the storm visibility was limited to less than 200 m. The rectangular filter head of the high volume dust sampler is shown in the center part of the pictures.

Appendix – Abstracts of the project derived publications

Herut B., Collier R. and Krom M.D. (2002). The role of dust in supplying N and P to the SE Mediterranean. *Limnol. Oceanog.* 47: 870-878.

Abstract
This study assesses the role of the atmospheric dry fallout as a source of new nitrogen and phosphorus to the surface Levantine seawater. Leaching experiments of inorganic nitrogen ($LINO_3^-$, $LINH_4^+$) and phosphorus ($LIPO_4$), using SE Mediterranean surface seawater, were performed on 41 aerosol (hereafter 'dust') samples collected on Whatman 41 filters between April 1996 and January 1999 at Tel Shikmona, Israel and on 4 desert-event dust powder samples. A geometric mean of 2.8 and 3.2 mmol NO_3^- and NH_4^+ per g of dust were leached by seawater from normal (background) dry deposition captured by the filters. Significantly lower amounts of IN with lower NH_4^+/NO_3^- ratios were leached from both the filters and the dust powder sampled during dust events (mean of 0.18 and 0.02 mmol NO_3^- and NH_4^+ per g of dust). Similarly, relatively lower values of $LIPO_4$ were measured in desert type events, attributed to systematic decrease in IP solubility with increased rock/soil component. The calculated $LINO_3^-$ and $LINH_4^+$ fluxes were 34 and 20 mmol m^{-2} yr^{-1} from normal dry deposition, 2.5 higher than the wet IN deposition, and twice the riverine input (23 mmol m^{-2} yr^{-1}, Guerzoni et al. 1999). This high ratio is due to the semi-arid climate in this basin. The estimated flux of total dry IP was 1 mmol P m^{-2} yr^{-1} approximately 3 times higher than the input of wet IP, and somewhat lower than the estimated riverine input (1.4 mmol m^{-2} yr^{-1}, Guerzoni et al. 1999). The similarity of atmospheric and burial fluxes of P in the Levantine basin reinforces the hypothesis that the atmosphere is the dominant source of P to the sediments in the deeper parts of the basin. It was estimated that the leachable fluxes of IP and IN (dry+wet) can support between ~15 or ~70% (1-4 g C m^{-2} yr^{-1}) of the new production in the SE Mediterranean, effective mainly during dust events and stratification. This input may contribute significantly to the relatively high N:P ratios in Levantine deep water (~27).

Herut B. (2004). Atmospheric input of inorganic N and P to the SE Mediterranean, comments on total and bioavailability assessment. In: A. Yilmaz (ed.), Oceanography of the Eastern Mediterranean and Black Sea, Tubitak Publishers, Ankara, Turkey, pp 229-235.

Abstract
This note aims to emphasize the importance of dry and wet atmospheric fallout as a source of new nitrogen and phosphorus in the East Mediterranean, and the constraints related to this assessment. This basin is characterized by high variability of atmospheric wet and dry fluxes as depicted from long-term records of atmospheric material inputs. Apart from this variability in total nutrient inputs, the nutrient solubility in surface seawater (the bioavailable fraction) is highly dependent on the dry aerosol composition. In general, particles from Sahara/desert sources exhibit significantly lower solubility of inorganic P and N, and higher soluble N/P ratios as compared to particles associated with European/marine air masses. Thus, differences in relative contributions of particle sources may impact the assessment of bioavailable inputs. Preliminary measurements indicate that the dissolved organic fraction should be also considered in the latter estimate. While the present estimates provide essential values, they are still subjected to uncertainties. Improved knowledge regarding spatial and temporal variability of the aerosols and their chemical characters across the basin plus the magnitude of nutrient influx from other sources and sinks gives key information in quantifying input fluxes.

Herut, B., Krom, M. and Carbo, P. (2004). Atmospheric input of nutrients, impact on East Mediterranean waters. *Rapp. Comm. Int. Mer. Medit*. 207.

Abstract
In the long-term, atmospheric deposition (especially dry fallout) play an important role in the supply of new nitrogen and phosphorus to surface water in the East Mediterranean, and contributes significantly to the relatively high N:P ratios in Levantine deep water. In the short-term, while clear fertilizing response was observed in an on-board dust gradient microcosm experiment, no such field response was seen through a dust storm event. More detailed field measurements are required during dust events before clear conclusion can be made on their short-term impact.

Kocak M., Nimmo M., Kubilay N. and **Herut B.** (2004). Spatio-temporal aerosol trace metal concentrations and sources in the Levantine Basin of the Eastern Mediterranean. *Atmos. Environ.* 38: 2133-2144.

Abstract
The current study considers the spatial and temporal variability in aerosol trace metal concentrations (Al, Fe, Mn, Cr, Cu, Pb, Cd, Zn) in the Levantine Basin of the Eastern Mediterranean, utilising an extensive sample library (n=621) collected between 1999-2001, at two coastal sites located at the northern, Erdemli (Turkey) and southeastern, Tel Shikmona (TS, Israel), region of the Basin. A critical evaluation of the datasets from the two locations was presented. Enhanced concentrations of Al (1.7x), Fe (1.8x), Mn (2.1x) were detected at the more southerly sampling station, during common dust events, owing to the greater proximity of desert dust sources (NE Africa and Saudi Peninsula); leading to a gradual decline in crustal inputs northwards across the basin. An insignificant Pb gradient was noticed across the Levantine Basin, which has exhibited a decadal decrease (40%). Cr was enriched in the north by a factor of three accounted by local sources. Cu was also enriched, to a lower extent, by about a factor of two. Seasonal variations of the crustal elements (Al, Fe, Mn) at Erdemli were detected (transitional>summer>winter) owing to both, a greater frequency and intensity of dust events during the transitional period and a greater washout effect during winter. It is likely that similar variations occur at TS as both sites experienced similar dust and rainfall events. It was observed at Erdemli that all elements (except Pb and Cd) exhibit their lowest concentrations in the winter period due to a greater washout effect. The lack of seasonal difference between winter and summer for Pb and Cd may have been due to the relatively high emission intensities of regional sources rapidly regenerating aerosol concentrations and their association with fine particles which are less efficiently scavenged during rain events. During the summer, Zn derived from local transportation and agricultural activities, was more pronounced, leading to an enhancement of around 10% in its concentration.

Krom M.D, **Herut B.** and Mantoura F. (2004). Nutrient budget for the Eastern Mediterranean: Implications for P limitation. *Limnol. Oceanog.* 49: 1582-1592.

Abstract
The Eastern Mediterranean has a high nitrate to phosphate (N:P) ratio (~28:1) in the deep water and a highly unusual P limitation of the primary productivity. We present a detailed nutrient budget of inputs to the basin, which showed that there is a high N:P ratio (>16:1) in all the input sources, but particularly from the atmospheric source where the N:P ratio was 117:1. The high N:P ratio is retained within the system because there is no significant denitrification in either the sediments or intermediate water. This is because of the extreme oligotrophic nature of the system caused by the unusual anti-estuarine flow at the Straits of Sicily. Support for this conclusion is provided by the observation that the only area of the Eastern Mediterranean where the N:P ratio in deeper water is ~16:1 is the northern Adriatic, which is also the only area with significant denitrification. The N budget (total input to basin compared to net output at the straits of Sicily) balances closely. This N balance suggests that

N fixation is an insignificant process in this P limited system. The unusually light ^{15}N values in the deep water nitrate and PON, which have been found by Sachs and Repeta (1999) and Pantoja et al. (2002), can be explained by processes other than nitrogen fixation. These processes include a lack of significant denitrification in the basin and by POM exported from surface waters during the P limited winter plankton bloom.

Koçak M., Kubilay N., **Herut B.** and Nimmo M. (2005). Dry atmospheric fluxes of trace metals (Al, Fe, Mn, Pb, Cd, Zn, Cu) over the Levantine Basin; A refined assessment. *Atmos. Environ.* 39: 7330-7341.

Abstract
The current work presents dry deposition fluxes of trace metals to the Southern and Northern Levantine Basin of the Eastern Mediterranean Sea. The dry depositional rates were calculated taking into account (i) the spatial gradients in metal concentrations across the Levantine Basin, (using trace metal aerosol concentrations from two location, Erdemli, Turkey and Tel Shikmona, Israel over a three year sampling period) (ii) the air mass origins (iii) air mass temporal influence across the N and S Levantine basins and (iv) fine / coarse elemental aerosol size distributions to calculate realistic elemental settling velocities. Two distinct airflow sectors were defined at each site; North (N) and southwest (SW), having different temporal influences at each site (the temporal ratio of SW:N was 1.85 and 0.43 at Tel Shikmona and Erdemli respectively). Temporal airflow weighted aerosol concentrations were then calculated for each site. The applied settling velocities calculated using size fractioned aerosol samples (n=227) collected from Erdemli and from the literature, yielded higher (compared to previous work) settling velocities for Cu, Pb, and Zn being 1.1., 0.8 and 0.9 cms^{-1} respectively. Total dry deposition fluxes for the crustal elements (Al, Fe and Mn) were consistent with previous studies for the region, however Cu, Pb, Cd, and Zn were much higher, in part, due to the larger adopted settling velocities. Using sequential leach data, the exchangeable as well as total elemental dry inputs were presented for both the north and south Levantine basins. Comparison with literature wet deposition would suggest that the dry deposition pathway is a more significant input for Cu, Pb, Cd and possible Al and Fe. The leachable dry atmospheric inputs of Pb, Cu and Cd to the southern basin were orders of magnitude greater in significance than riverine inputs. A similar comparison could not be made for northern basin owing to limited riverine input data.

Carbo P., Krom, M.D., Homoky W.B., Benning L.G., **Herut B.***, (2005). Impact of atmospheric deposition on N and P geochemistry in the southeastern Levantine basin. *Deep-Sea Research*
*** corresponding author**

Abstract
Aeolian dust was collected from 2001 to 2003, as part of a longer term study, to estimate the nutrient input to the Levantine basin from atmospheric deposition. Adsorption experiments, using dust samples from 6 individual dust storms, showed insignificant adsorption of phosphate onto dry deposited Saharan dust. Thus adsorption onto dust can be discounted as a reason for the high nitrogen:phosphorus (N:P) ratio in the deep water of the eastern basin. A single dust storm sample from the Western Mediterranean was able to adsorb some phosphate from seawater, and it is speculated that this may be linked to the action of acid aerosols on the dust during cloud formation, or to the varying chemical composition in different sources of dust.

Dry atmospheric deposition is an important net supplier of both N and P to the eastern basin. Leachable inorganic nitrogen concentrations and fluxes are higher in background (non storm)

samples than in storm samples, probably due to the smaller grain size and aerosol source. Total P is supplied naturally with the dust, as shown by the close correlation between total P and Al ($r^2 = 0.95$). However, there is a poor correlation between leachable inorganic P (LIP) and Al ($r^2 = 0.20$), which may be related to grain size effects and/or recycling processes in the atmosphere. Even so, the supply of LIP to surface waters is greatest during dust storms due to comparatively high deposition of aerosol material. While atmospheric input of P during dust storms does not produce significant *in-situ* increases in chlorophyll, probably due to rapid microbial grazing, it does represent an important proportion of the long-term nutrient input to the basin. This may be increasing as the frequency of dust storms increases.

Herut, B. , Krom, M.D. , Law, C., Mantoura, R.F.C., Pitta, P., Psarra, S., Rasssoulzadegan, F., Rees, A., Thingsted, F., Tanaka, T., Zohary, T (2005). Response of East Mediterranean surface water to Saharan dust: on-board microcosm experiment and field observations**.** *Deep Sea Research.*

Abstract
An on-board microcosm experiment was performed during the CYCLOPS May 2002 cruise to track the biogeochemical response of Eastern Mediterranean surface seawater to a gradient addition of fresh and pre-leached Saharan dust, mimicking the potential fertilization effect as opposed to the impact of adding particles alone. Response parameters examined were P turnover time, bacterial production and abundance, chlorophyll a, other phytopigments, abundance of different pico and nanophytoplankton groups, primary production rates, abundance of heterotrophic nanoflagellates and ciliates. The addition of fresh Saharan dust (range: 0.2 to 4.9 mg l^{-1}) and the subsequent nutrient release triggered an increase in phytopigments and primary production, while no response was detected for pre-leached dust particles. Most responses were linearly related to the amount of fresh dust added. *Synechococcus* and prymnesiophytes increased in abundance and cellular pigment content while *Prochlorococcus* disappeared, heterotrophic bacteria increased production rates, and ciliates showed a small increase in cell density. A less clear response was recorded by *in-situ* measurements following a Saharan dust storm during a cruise in the Levantine Basin in May 2001. The calculated amount of nutrients and dust particles delivered by such an event to a 15 m thick mixed surface layer is low (~0.3 nmole P l^{-1}, ~9 nmole N l^{-1} and 0.06 mg dust l^{-1}), falling close to the lowest dust addition in our microcosm experiment. Even so, an enhancement of phosphate turnover time, a sharp decline of *Prochlorococcus* abundance, and slight increases in chlorophyll a and bacterial activity were observed in response to the dust storm. Considering the linear effect of fresh dust concentrations on the bacterial activity, primary production and pigment concentration (total and per cell), and the likely stimulation of grazing it is not surprising that changes due to moderate strength dust storms are mostly close to detection limit of either field or remote sensing measurements.