

normal in the intermediate (16.97) and higher in the deep waters (36.18) as compared with that of Redfield's (16). Whereas, TN:TP ratios were found high with no big variations between different water masses. The relationships between different investigated variables were evaluated and statistically confirmed. Based on the recent observations that revealed significant changes in salinity and temperature structures for the Eastern Mediterranean deep waters, the data of the present study can serve as a reference to assess any future changes in the chemical composition for the water mass of the south eastern Mediterranean Sea.

INTRODUCTION

The circulation and formation of water masses in the Eastern Mediterranean is recently characterized by the transient phase (Roether *et al.*, 1996; Malanotte-Rizzoli *et al.*, 1997, and Klein *et al.*, 1999). Accordingly, the main objectives of the oceanographic investigations are to assess the adaptation in a new state of equilibrium and to quantify the impact of these changes on the biogeochemical characteristics. Within the framework of these objectives, Meteor cruise M51/2 program was carried out along the Eastern Mediterranean during October-November 2001. The present study is a part of this cruise program and aims to describe the hydrochemical and nutrient properties of different water masses for the southeastern Mediterranean Sea in front of Egypt. It will address the question of potential nutrient limitation and N:P, ratios found at different water masses in the area. The present data can serve as a reference to assess the future changes in the chemical composition of the water masses in the southeastern Mediterranean Sea. Previously, the chemical characteristics of the Eastern Mediterranean have been studied on a limited basis (Morcos, S.A. and El-Rayis O.A. 1973; Abdel Moati, 1990; Salihoglu *et al.*, 1990; Souvermezoglou *et al.*, 1992; Yilmaz *et al.*, 1994; Yacobi *et al.*, 1995 and Kress and Herut, 2001). Hecht *et al.* (1999) characterized four water masses in the northern Levantine Basin, based mainly on climatological, salinity and water depth values: Levantine surface water (LSW of $S_{\text{‰}} = 38.95$, 0-40m), Atlantic water (AW of $S_{\text{‰}} = 38.87$, 65-95m), Levantine Intermediate water (LIW of $S_{\text{‰}} = 38.94$, 200-310 m) and Deep waters (DW of Temp. $< 13.8^{\circ}\text{C}$, $S_{\text{‰}} < 38.74$, below 700m). These depth intervals was used to classify different water masses of the present investigation.

MATERIAL AND METHODS

Four stations located between latitudes $32^{\circ} 31' 22-33^{\circ} 14 91$ N and longitudes $25^{\circ} 31' 10-29^{\circ} 59 84$ E were selected north of Rosetta Branch of the River Nile (546), north of Dabaa (548) and north of Saloum (549 and 550) to represent the southeastern Mediterranean waters in front of Egypt (Fig. 1). The profiles of water temperature, salinity and dissolved oxygen were measured in situ at each station by using a Neil Brown CTD. Dissolved oxygen saturation were computed using UNESCO Tables (1973). Pigment measurements were obtained by a fluorometer connected to the CTD. Water samples for the nutrients were collected with a general Oceanic Rosette equipped with 24 Niskin bottles of 5L each. Water samples were selected from about 12 depth at each station to present different water masses of the represent investigation. Water samples were collected into 250 ml acid washed polyethylene bottles, after washing them several times with the same water sample then immediately frozen until analysis. Ammonium ($\text{NH}_4\text{-N}$), was determined by using the indophenol blue technique (IOC, 1983). Nitrite ($\text{NO}_2\text{-N}$), nitrate ($\text{NO}_3\text{-N}$), reactive phosphate ($\text{PO}_4\text{-P}$) and silicate ($\text{Si}_2\text{O}_4\text{-Si}_i$) were measured in filtered seawater samples (by using GF/C filters) following the techniques described by Strickland and Parson (1972). Total phosphorus (TP) and total nitrogen (TN) were measured in unfiltered seawater samples according to Valderrama (1981). Dissolved inorganic nitrogen (DIN) concentrations were calculated ($\text{DIN} = \sum \text{NH}_4\text{-N} + \text{NO}_2\text{-N} + \text{NO}_3\text{-N}$). Synthetic standards as well as international reference materials (batch VKI 9-2-0894 for $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and $\text{PO}_4\text{-P}$ and batch 10.2-0894 for TP and TN) were intended for quality control i.e. they typically intended for measurement and control of the truness and precision of analysis, as well as for the implementation and optimization of analytical instrument and methods.

T. test and Anova at the 95% confidence level were used in statistical comparisons for the chemical characterization of the water body.

RESULTS

The average values of different hydrochemical characteristics along the water masses of each station as well as for the whole investigated region are listed in Tables 1-3. Their profiles for the whole water column as well as for the upper 500m depth of each station are represented in Figs 2-4. The general features of different water masses can be identified as the following:

Levantine surface water (LSW)

The levels of surfacial water temperature (upper 40m depth) were found around the normal values of autumn season. They registered a mean value $23.0 \pm 0.72^{\circ}\text{C}$ for the whole investigated region. No big differences were found between salinity values of different stations. Dissolved oxygen (DO) was fairly constant across the region and reached around saturation condition. The levels of flurometer measurements were generally, low. The limits of different inorganic nitrogen forms (DIN), (ammonium, nitrite and nitrate), dissolved inorganic phosphorus (DIP) and reactive silicate were, generally poor. Slight increase in DIN concentration ($1.30\mu\text{M/l}$) was detected at El Saloum (station 550) as compared to the other locations. The geographic distribution of total nitrogen (TN) concentrations registered a noticeable increase westward giving a mean value $25.38 \pm 3.79 \mu\text{M/l}$ for the whole surfacial water of investigated region. DIN constituted a mean value $3.81 \pm 0.53\%$ of TN revealing the increase in consumption and deposition rates for these inorganic constituents. DIP was found below the limit of detection at stations 546 and 547 and slightly measured westward at stations 549 and 550 ($0.12\mu\text{M/l}$). Total phosphorus (TP) had two noticeable features; a slight variations from a mean $0.53 \pm 0.18 \mu\text{M/l}$ recorded at most locations and an elevated value $5.78\mu\text{M/l}$ found at station 549. This value was higher than the actual region levels, consequently it excluded from the DIP overall mean value calculations. DIP/TP percentages showed variations with a strong gradient from a value of zero at stations 546 and 548 to a value of 18.46% at station 550.

Atlantic water (AW)

The characteristic features of AW when compared with that of LSW, it showed slight decrease in the salinity values and increase in DO% saturation, accompanied with the relative increase in flurometer measurements. At the same time, it followed LSW in which DIN, DIP and $\text{S}_2\text{O}_4\text{-S}_2$ were homogeneous

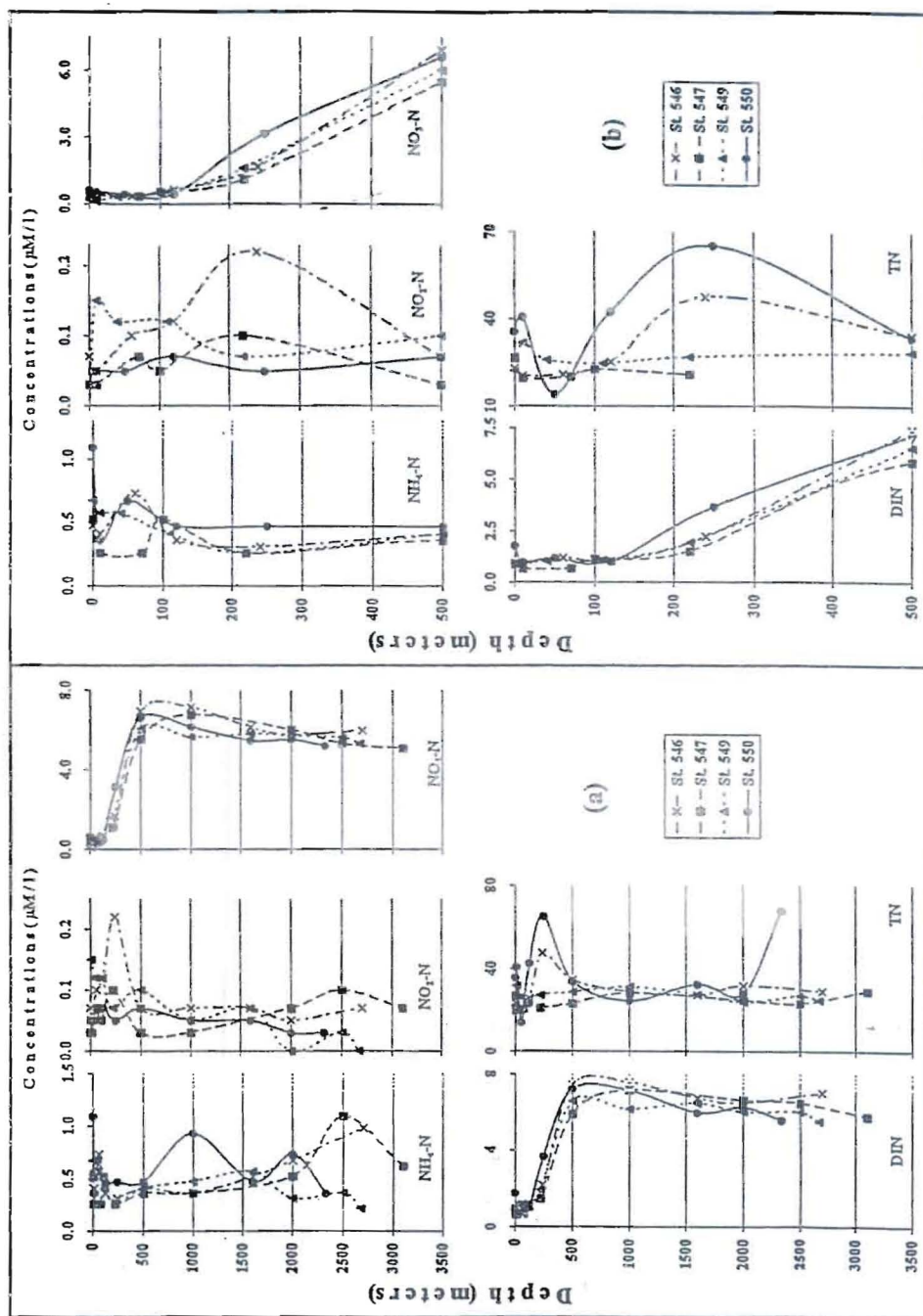


Fig.3: The depth profile of studied nitrogen forms for the whole water column (a) and upper 500m depth (b) of the southeastern Mediterranean waters in front of Egypt during November 2001

Table 1: The average values of some hydrographical parameters at different water masses of the southeastern Mediterranean Sea in front of Egypt during November 2001

Water masses	Temperature	Salinity	DO	DO Saturation	Fluorometer measurements
	(°C)				
St. 546					
LSW	23.90	39.20	4.61	97.9	0.027
AW	21.10	38.91	5.03	101.3	0.059
LIV	17.25	39.03	5.22	98.3	0.008
DW	13.96	38.79	4.44	78.3	0.003
St. 547					
LSW	22.44	39.13	4.82	99.9	0.031
AW	18.50	38.79	5.30	102.0	0.055
LIV	16.73	39.05	5.06	94.3	0.014
DW	14.04	38.81	4.46	78.7	0.005
St. 549					
LSW	22.39	38.99	4.87	100.7	0.034
AW	18.06	38.66	5.29	100.9	0.094
LIV	16.28	39.04	5.01	92.6	0.008
DW	13.98	38.80	4.47	78.7	0.004
St. 550					
LSW	23.28	39.17	4.65	97.9	0.036
AW	23.13	39.14	4.64	97.3	0.037
LIV	15.49	39.02	4.89	89.0	0.008
DW	13.89	38.78	4.47	78.7	0.002
Whole investigated region ± STD					
LSW	23.00 ± 0.72	39.12 ± 0.09	4.74 ± 0.13	99.1 ± 1.4	0.032 ± 0.004
AW	20.12 ± 2.37	38.87 ± 0.20	5.07 ± 0.31	100.4 ± 2.1	0.061 ± 0.024
LIV	16.44 ± 0.75	39.04 ± 0.01	5.05 ± 0.14	93.5 ± 3.9	0.010 ± 0.003
DW	13.97 ± 0.06	38.80 ± 0.01	4.46 ± 0.01	78.6 ± 0.2	0.004 ± 0.001

Table 3: The average values of studied phosphorus forms and reactive silicate at different water masses of the southeastern Mediterranean Sea in front of Egypt during November 2001

Water masses	DIP ($\mu\text{M/l}$)	TP	DIP/TP (%)	N/P (Ratio)	TN/TP	SiO ₄ -Si ($\mu\text{M/l}$)
St. 546						
LSW	ND	0.61	-	-	35.60	0.38
AW	ND	0.57	-	-	40.40	0.47
L1W	ND	28.98	-	-	1.63	0.57
DW	0.13	0.78	16.67	49.08	38.50	5.38
St. 547						
LSW	ND	0.33	-	-	69.80	0.48
AW	0.11	0.53	20.76	4.18	40.40	0.90
L1W	ND	0.98	-	-	21.18	1.13
DW	0.13	0.59	22.03	44.07	42.86	5.23
St. 549						
LSW	0.12	5.78	2.08	1.67	4.60	0.44
AW	0.07	1.63	4.30	7.86	15.12	0.28
L1W	0.14	0.73	19.18	11.43	36.88	0.28
DW	0.20	0.55	36.36	28.40	48.93	6.41
St. 550						
LSW	0.12	0.65	18.46	4.58	46.40	0.57
AW	0.07	0.73	9.59	6.57	58.19	0.28
L1W	0.14	0.81	17.28	22.50	80.47	2.17
DW	0.25	7.57	3.30	23.16	4.90	6.26
Whole investigated region \pm STD						
LSW	0.06 \pm 0.07	0.53 \pm 0.18	10.27 \pm 11.58	3.12 \pm 2.06	39.10 \pm 27.07	0.47 \pm 0.08
AW	0.06 \pm 0.04	0.86 \pm 0.52	11.55 \pm 8.40	6.20 \pm 1.87	38.53 \pm 17.72	0.48 \pm 0.29
L1W	0.07 \pm 0.08	0.84 \pm 0.13	18.23 \pm 1.34	16.97 \pm 7.83	35.04 \pm 33.54	1.04 \pm 0.83
DW	0.18 \pm 0.06	0.64 \pm 0.13	19.59 \pm 13.68	36.18 \pm 12.37	33.80 \pm 19.73	5.82 \pm 0.60

ND=not detected

DISCUSSION

The distribution pattern of hydrochemical and nutrients characteristics, in the investigated region are generally controlled by an interaction or balance between the circulation and biological activity. It is reported that, the AW enters the eastern Mediterranean through the strait of sicily and its salinity and depth increase as it flows eastward. In summer because of increased evaporation, the AW is capped with a layer of salter and warmer water, the LSW. In winter AW is essentially the LSW. LIW is formed in the Levantine Basin and flows into the western Mediterranean and from there to the Atlantic ocean (POEM, 1992). DW of the Eastern Mediterranean are derived to a large extent from the Aegean Sea which replaced or masked the Adriatic derived deep waters (Roether *et al.* 1996; Klein *et al.*, 1999 and Malanotte Rizzoli *et al.* 1997). In the present study, the distribution of oxygen in the upper 120m of the water body was fairly around saturation condition, a shallow oxygen maximum was present at 60-120m depth, in conjunction with the relative increase in fluorometer measurements and consequently, in photosynthetic process at this water layer (Fig. 2). Kress and Herut (2001) found an oxygen over saturated condition between the same water layer of the Eastern Mediterranean. They attributed it to the physical process of rapid capping and trapping of oxygen in the AW, with only 28% of the excess oxygen originating from biological production. The euphotic zone was also characterized by poor DIN, DIP and $S_iO_4-S_i$ concentrations due to the uptake by phytoplankton. DIP seldom achieves concentrations comparable to those of NO_3-N because it is strongly adsorbed onto particles and forms insoluble salts (Krom *et al.*, 1991) while NO_3-N is highly soluble. In general, the mean concentrations of these nutrients in the LSW and AW had relatively very high standard deviations due to the low levels measured (Tables 2-3). Based on the above, the euphotic zone of the present study maintains its oligotrophic character throughout the autumn with concentrations lower than $0.1\mu M/l$ PO_4-P (Karafistan *et al.*, 2002), and about $0.50\mu M/l$ for each of NH_4-N and NO_3-N (Skrivanic and Strin, 1982). New nutrients can be supplied to the euphotic zone by processes such as upwelling and erosion of the thermocline from below as well as from the atmospheric deposition. By using the PEM model of Karafistan *et al.* (2002), they found that upwelling of the Mediterranean water brings about 5.5×10^{10} mol y^{-1} of phosphate to the upper layer located between 0-200m. Herut *et al.* (1999) reported an atmospheric input for N and P of 0.24 and 0.01 gm $m^{-2} y^{-1}$, respectively.

Except few occasions, the vertical distribution pattern showed no significant differences for each of TN and TP concentrations at different water masses of study region. They tend to remain fairly constant to the sea bottom. Reflecting that TN and TP can not accumulate in deep waters nitrogen and phosphorus are taken up in the euphotic zone and released back into sea water following the remineralization of sinking detritus, and the concentrations build up in deep water from which they can be brought to the surface again via upwelling.

Statistically, there are well established positive relationships between depth and each of nitrate, reactive silicate and phosphate. These associations were significantly negative with fluorometer measurements (FLC) and DO% (Table 4). Highly negative associations found between FLC and each of nitrate and reactive silicate concentrations, may suggest that, the dominant role of phytoplankton consumption cannot be neglected in the euphotic zone. Linear relationship of nitrate was found highly significant with reactive silicate (+0.957) than that of phosphate (+0.539). They confirm the role of organic matter remineralization in decreasing the DO% and increasing the nutrient concentrations with depth, and the rate of nitrate and reactive silicate production is higher than that of phosphate. These relationships can be represented by the following regression equation:

$$\begin{aligned} \text{DO} = & 0.190 \text{ Depth} - 0.719 \text{ Temp.} + 0.060 \text{ FLC} - 1.245 \text{ NO}_3 + 0.060 \text{ TN} - \\ & 0.053 \text{ DIP} \\ & + 0.058 \text{ TP} - 0.611 \text{ SiO}_4 \\ (\text{R} = & 0.951, \text{P} < 0.000, \text{Std Error of Estimate} = 0.088). \end{aligned}$$

N:P ratios

From nitrate versus phosphate trend at different locations of the present study, neglecting N/P values when P was below detection limit, there was a marked differences between different water masses with ratios changing from much lower in the euphotic zone (3.12), normal in the LIW (≈ 16.97) and higher in the DW (36.18) as compared with that of Redfield's (16). Whereas, TN/TP ratios were found high with no big differences between different water masses (Table 3). It revealed that the phytoplankton production in the euphotic zone was strongly nitrogen limited. This result is varied than that of Krom *et al.* (1991) who claimed phosphorus as the most limiting nutrient to phytoplankton production in the Eastern Mediterranean, but it is in agreement with that of Falkowski *et al.* (1997) who argued that the world oceans are generally N-limited and that N₂ fixation plays a key role in reintroducing fixed nitrogen to

the ocean. However, high N/P ratios recorded in DW of the present study could be as the result of the organic matter being remineralized in the DW is poor in phosphorus due to its faster recycling in the photic zone compared to nitrogen (Kress and Herut 2001). Gruber and Sarmiento (1986) nominated that DW of the Mediterranean origin can be traced in the Atlantic ocean by the high N/P ratios. Small variations, found between TN/TP values may confirm the absence of their accumulation at different water masses.

Stratford and Haines (2002), studied the impact of the event on both biogeochemical tracer distributions and modelled export production between 1987 and 1995. They suggested that the transient event has little impact on export production of the Eastern Mediterranean Sea. The data of the present investigation can serve as a reference for assessing future changes in the chemical composition of the water mass in the southeastern Mediterranean Sea.

CONCLUSION

The hydrochemical and nutrients characteristics for different water masses of the southeastern Mediterranean Sea in front of Egypt were investigated, to fill the gap in information about this region. The obtained, data were discussed and evaluated. Based on the recent observations revealed significant changes in salinity and temperature structures of the Eastern Mediterranean deep waters, the data of the present study can serve as a references for assessing future changes in the chemical composition of water masses in the southeastern Mediterranean Sea.

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