

Impact of wind on the dispersion of contaminants in the Lebanese northern marine area

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Abstract

Batroun coastal marine zone – North Lebanon – is subjected to the discharges of two terrestrial sources of contamination, the phosphate plant of Selaata and Al-Jaouz River. In the aim to study their impact on the horizontal variability of sea water characteristics at short spatio-temporal scale, the displacement of water masses was followed under different wind conditions through the movement of a free drifting drogue. The wind regime played an essential role in the displacement and spreading of various contaminants over a wide area. The impact of Selaata chemical plant was shown not to be limited to Batroun marine area but its impact may invade further neighbouring northern marine area of the Lebanese coast.

Keywords: Lebanon, Drifting drogue, Wind, River, Phosphate plant.

Introduction

The coastal marine zone of Lebanon is strongly affected by multiple sources of contamination, which discharge directly in sea water without any pretreatment. These contaminants may cause eutrophication when referring to elevated concentrations of nutrients or may subject marine

pelagic and benthic organisms to lethal effects due to their heavy load with poisonous material (low pH, undesirable heavy metal, PAH derivatives, high temperature, etc...). The presence of various outflows inside the same coastal zone, with their complex interactions, enhances the difficulties to discriminate the sources in order to assess an efficient environmental policy. Batroun coastal marine area (North Lebanon) represents such a complex hydro-system that receives the waters of two terrestrial sources: those of the Al-Jaouz River, fresh and rich in nitrate, and those of Selaata's fertilizers plant, acidic and rich in phosphate. The Al-Jaouz is a Lebanese river with a typical Mediterranean hydrological regime with a seasonal rhythm of alternate strong flows due to often violent risings in spring and a complete dryness in summer and autumn (Abboud-Abi Saab *et al.* 2002). The other factor of variation is the permanent and non periodic contribution of Selaata's chemical factory (Fakhri *et al.* 2005). The dynamic in space and time of the discharges from the two sources depends on their proper functional rhythm and flow's intensities, and on the prevailing wind which is subjected to a seasonal dominance in force and direction (Anonymous 1970).

The variability of some of the physico-chemical characteristics of a complex hydro-system on a short spatio-temporal scale may be coupled with the displacement and dispersion of water masses via a Lagrangian strategy (Lacombe 1965).

This research work aims to study the impact of the prevailing wind on the dispersion of contaminants discharged from the phosphate's plant and the river by following the variations of surface sea water characteristics at a short scale.

Materials and Methods

Sampling location

Batroun coastal area is subjected to the discharges of Al-jaouz seasonal river, active in winter and spring and dry in summer and autumn with annual mean flow of about 74 Mm³ and to those of Selaata chemical

plant with an annual mean production capacity of about 765 thousand tons of multiple products mainly phosphate fertilizers, and phosphoric and sulphuric acids (Yager 2005). The river's mouth is located 500 m to the north of the plant's installations. A 500 m long jetty is raised at 200 m to the north of the plant.

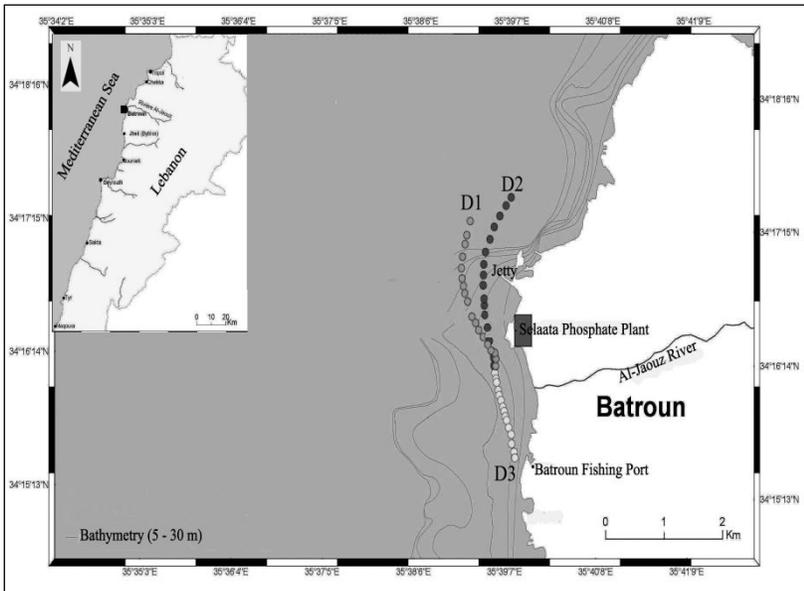


Figure 1. The site of the study area and the routes followed by the drifting drogue during the 3 experiments (D1- April 2003; D2 - June 2003; D3 - October 2003).

Sampling strategy

The sampling route was chosen according to the movement of a simple designed free drifting wooden and cross-shaped drogue (Monahan and Monahan 1973) with 4 internal surfaces of 0.5 m² each, covered with thick polyethylene sheets and that is able to move generally in the bed of the prevailing wind Niebauer *et al.* (1995). The drogue was deployed in Batroun coastal water at an equal distance from both the chemical factory and the River's mouth (N34°16.187', E35°39.052') in April, June and October 2003 under different wind conditions (Figure 1). Wind speed

and direction data were provided by a Davis type (Monitor II) weather station located 1 km to the south of the point of deployment. During each experiment, the drogue was followed for 2 hours from 8:00 till 10:00 o'clock morning with a small fishing boat. Every 7 minutes, the boat approached gently the drogue to record its geographic position and to collect water samples.

Analysis

Water temperature was measured in situ with a multiparameter probe (type WTW). Salinity was measured at the laboratory with a benchtop induction salinometer type Bekman based on practical salinity scale. The orthophosphate (P-PO₄) was analyzed according to the colorimetric method of Murphy and Riley (1962) and the nitrate (N-NO₃) levels in water samples were determined according to Bendschneider and Robinson (1952) method by the measurement of nitrite ions (NO₂⁻) after the reduction of nitrate ions (NO₃⁻) by the passage of water sample through a cadmium column treated with copper (Wood *et al.* 1967).

Results

D1 - South-west wind experiment (April 2003)

During this experiment, the south-west wind (SW) was dominant with 8 km.h⁻¹ mean speed. The mean flow intensity of Al-Jaouz River during April 2003 was high with 45.63 Mm³.

The variations of water temperature and salinity during the whole drifting route of the drogue are illustrated in Figure 2 and those of nitrate and phosphate concentrations in Figure 3.

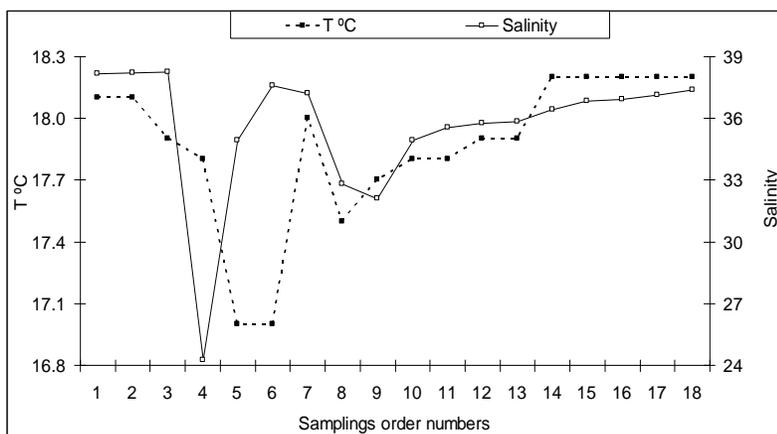


Figure 2. Temperature (°C) and salinity variations during the drift of the drogue in April 2003.

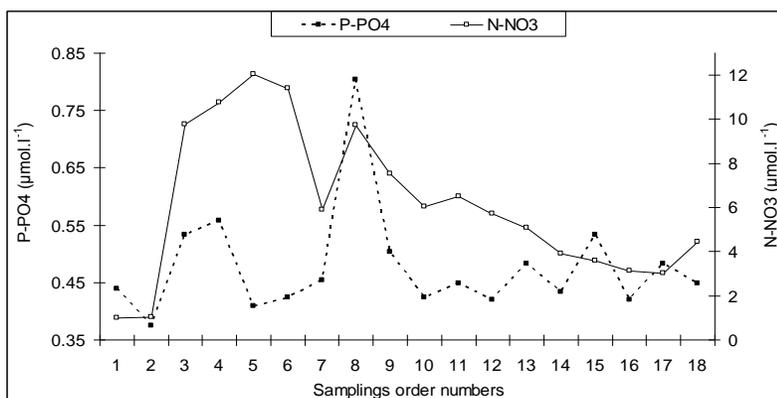


Figure 3. Orthophosphate and nitrate ($\mu\text{mol.l}^{-1}$) variations during the drift of the drogue in April 2003.

The first two points corresponded to water with Lebanese coastal marine characteristics usually measured during spring season in Lebanon (Abboud-Abi Saab *et al.* 2008) for salinity (38.17 and 38.22, respectively) and temperature (18.1°C) with expected corresponding low nitrate values (1.01 and 1.02 $\mu\text{mol.l}^{-1}$, respectively), but with unusually stronger levels of P-PO4 (0.44 and 0.37 $\mu\text{mol.l}^{-1}$, respectively). A sudden change in the direction of the drogue towards the north-north west (N-

NW) at the third point was coupled with a sharp decrease in both, salinity (24.26) and water temperature (17°C) and a significant increase in N-NO₃ concentration (9.78 $\mu\text{mol.l}^{-1}$). As the drogue was proceeding far away from the river mouth, the river's signature on salinity and nitrate fluctuations became smaller especially after the drogue has passed behind the pier of Selaata chemical plant. This was translated by an increase in water temperature from 17.9°C to 18.2°C and in salinity from 35.84 to 36.42 within short distance between point13 and point14. From point14 until the end of the experiment at point18, the river's influence was always detectable by its signature in salinity (36.42 to 37.39) and temperature (18.2°C) as well as the high concentrations of N-NO₃ (3.91 and 4.42 $\mu\text{mol.l}^{-1}$). But the values were lower than those measured at the first two sampling points. All along the drifting route the concentrations of P-PO₄ were lower than those of N-NO₃ but higher than those usually measured in the Lebanese coastal waters, ranging between 0.37 and 0.55 $\mu\text{mol.l}^{-1}$. A single noticeable increase in P-PO₄ concentration was observed at the 8th sampling point (0.80 $\mu\text{mol.L}^{-1}$) in front of the main outlet at the west-northern side of the factory where usually high P-PO₄ concentrations are measured (Fakhri *et al.* 2005).

D2 – South South East and South West winds experiment (June 2003)

In the experiment of June 2003 - D2 (Figure 1), when the drogue was deployed at 8:00 the wind was weak and blowing from the south-south east (SSE) at a mean speed of 2 km.h^{-1} . One hour later, at 9:00, and because of the establishment of sea breezes in relation to earth warming which is an expected dynamics for the coastal Mediterranean zones in summer season (Romano and Marquet 1991), the wind changed to become an active south-west wind (SW) with a mean speed of 12.5 km.h^{-1} . In June 2003, the cumulative Al-Jaouz river flow intensity was low (3.17 Mm^3).

All along the drogue's drifting route, the temperature and the salinity exhibited narrow range of variations (26.2°C to 26.6°C and 38.81‰ to 38.88‰, respectively - Figure 4). The concentrations of N-NO₃ measured at the different sampling points fluctuated between 0.24

$\mu\text{mol.l}^{-1}$ at point 4 and $0.58 \mu\text{mol.l}^{-1}$ at point 1 (Figure 5). These concentrations were low enough to be considered similar to those generally recorded in zones located out of the reach of the river's plume (Fakhri *et al.* 2005) but they might be slightly higher than those reported by Abboud-Abi Saab *et al.* (2004) for Lebanese coastal offshore waters considered as typically marine during summer season. As a matter of fact, the area covered by the displacement of the drogue was not influenced by the impact of the weak flow of the Al-Jaouz River.

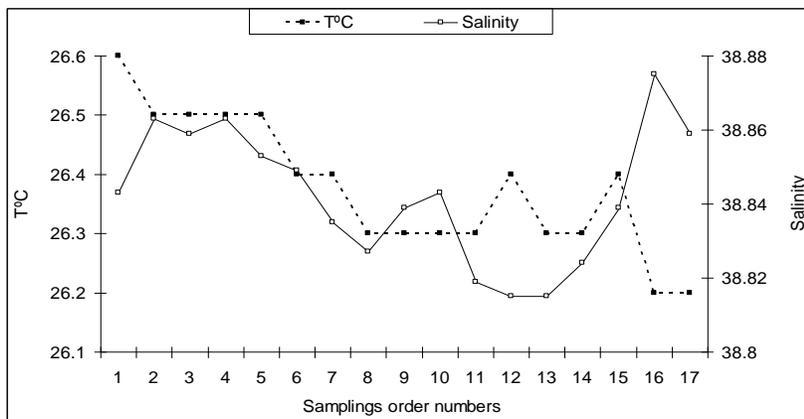


Figure 4. Temperature ($^{\circ}\text{C}$) and salinity variations during the drift of the drogue in June 2003.

The situation for P-PO₄ dynamic was totally different (Figure 5) and the concentrations increased progressively from $0.24 \mu\text{mol.l}^{-1}$ to $0.60 \mu\text{mol.l}^{-1}$ in the first six sampling points. After that the P-PO₄ concentrations increased sharply to reach a maximum value of $15 \mu\text{mol.l}^{-1}$ in front the main outlet when the drogue has penetrated inside the plume of factory's discharges heavily loaded with phosphate by products.

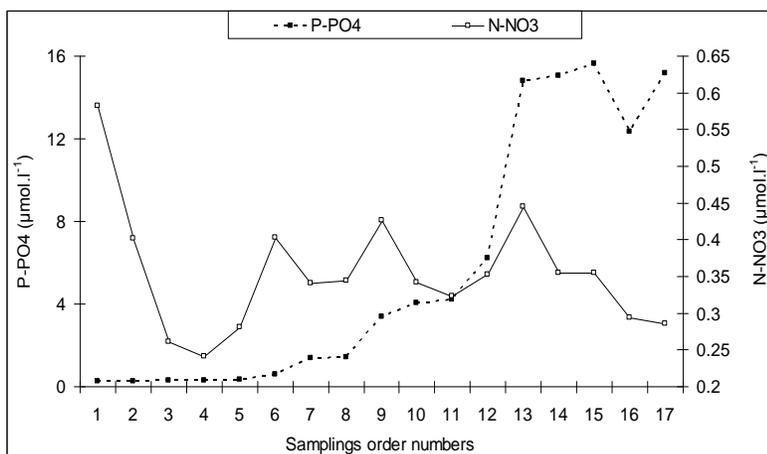


Figure 5. Orthophosphate and nitrate ($\mu\text{mol.l}^{-1}$) variations during the drift of the drogue in June 2003.

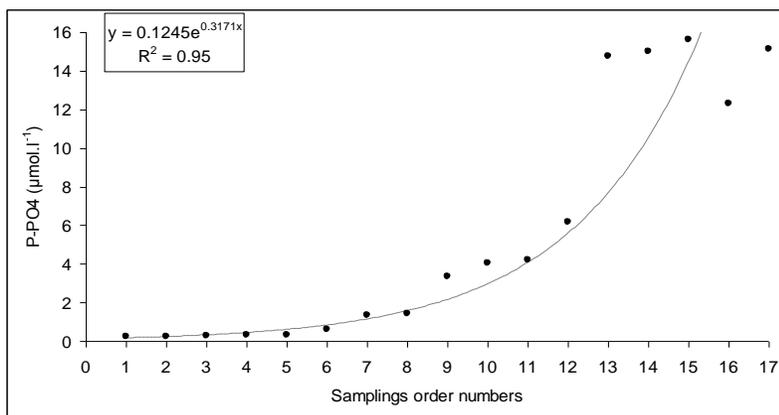


Figure 6. Relation between orthophosphate concentrations ($\mu\text{mol.l}^{-1}$) and samplings order numbers during the drift of the drogue ($r = 0.97$; $P < 0.001$; $k = 15$) in June 2003.

When the successive concentrations of orthophosphate were plotted in function of the corresponding sampling points (Figure 9), the best-tested curve adjustment obtained was an exponential type ($r = 0.97$; $P < 0.001$; $k = 15$), which is considered as well-adapted model to describe the dilution trend of an effluent in sea water. During this experiment, the permanent

activity of Selaata phosphate factory combined to the low concentrations of N-NO₃ because of the weak outflow of the Al-Jaouz River brought to this marine area an unbalanced budget of nutrients. This dynamic was not accompanied by any decline in salinity values since the factory uses in general the sea water for its cooling processes, and the eventual discharges of the fresh water out of the factory's outlets are very weak.

D3- Experiment under variable wind conditions (October 2003)

In the hours that preceded the onset of the experiment of October 2003 - D3 (Figure 1), the north wind (N) was dominant with a 4 km.h⁻¹ mean speed. At 8:00 when the drogue was deployed the wind changed to west south-west (W-SW) with a 3.2 km.h⁻¹ mean speed, then quickly it turned south wind (S) till the end of the drifting time with mean speed of 1.6 km.h⁻¹. In October the cumulative flow of the Al-Jaouz River was almost null (0.07 Mm³).

The examination of the physical parameters during the whole drifting route of the drogue (Figure 7) showed that the water temperature did not vary much, from 26.5°C at the beginning of the experiment till 26.7°C at the end of the drifting of the drogue and that the salinity values were almost steady, fluctuating tightly between 39.49 and 39.53.

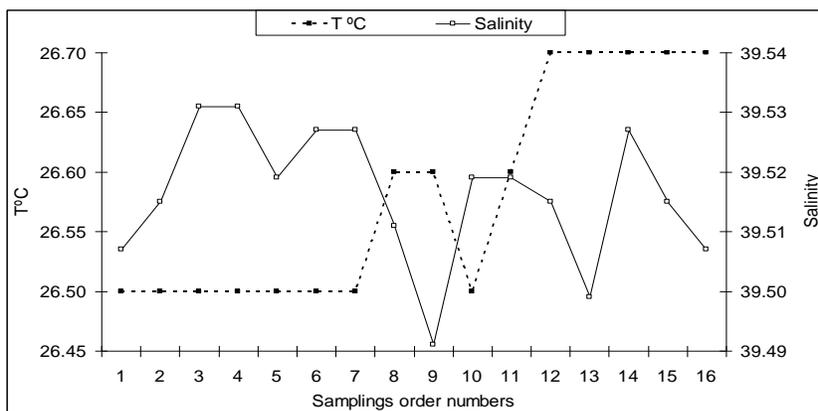


Figure 7. Temperature (°C) and salinity variations during the drift of the drogue in October 2003.

This regular evolution was disrupted by the presence of a high punctual concentration ($9 \mu\text{mol.l}^{-1}$) at the 7th sampling point, but the adjustment to an exponential model (Figure 9) is highly significant when this point is considered ($r=0.88$; $P<0.001$; $k= 14$), or discarded ($r=0.95$; $P<0.001$; $k= 13$).

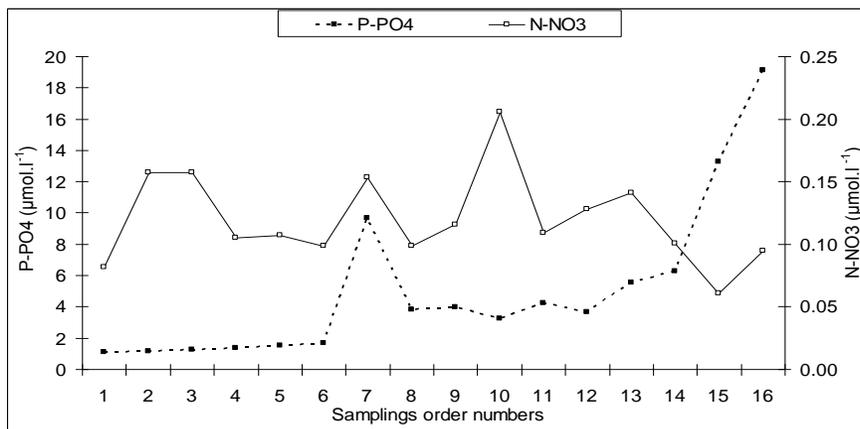


Figure 8. Orthophosphate and nitrate ($\mu\text{mol.l}^{-1}$) variations during the drift of the drogue in October 2003.

The chemical parameters (Figure 8) recorded a monotonous distribution for nitrate concentrations which they ranged between 0.06 to $0.21 \mu\text{mol.l}^{-1}$ but a different trend for the orthophosphate concentrations whose evolution was clear during the drogue's drifting; their concentrations increased progressively from $1 \mu\text{mol.l}^{-1}$ to more than $19 \mu\text{mol.l}^{-1}$ while proceeding away to the south of the factory.

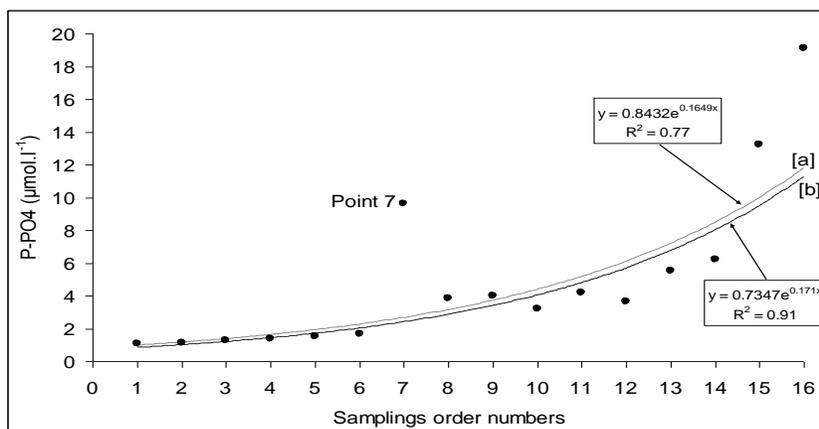


Figure 9. Relation between orthophosphate concentrations ($\mu\text{mol.L}^{-1}$ & samplings order points during the drift of the drogue in October 2003: trendline [a] with the 7th point ($r=0.88$; $P<0.001$; $k=14$); trendline [b] without the 7th point ($r=0.95$; $P<0.001$; $k=13$).

Discussion

Under the effect of the south-western wind (SW) conditions, the variations of the two seasonally inversely dependent factors, the salinity and the nitrate concentrations, showed that the river dilution's plume was spread far away to the north of the Al-Jaouz River's mouth. When the river is in its maximum flooding period (between December and May), its physical movement in association with wind effects becomes a basic component in the drifting of the dilution's plume. The nitrate-loaded freshwater as reported to be able to spread sufficiently far from the coast towards the North and to fertilize a whole region; a nutritive element considered essential for phytoplankton growth and reproduction especially in oligotrophic waters.

Under south-west wind conditions, when the factory is in its full production, the orthophosphate concentrations (P-PO₄), main signature of the Selaata's factory activity, appear to be present at a larger extent and dispersed far to the north like it was the case during the experiment of June 2003. The spread of orthophosphate-loaded water masses over a

quite large area is by itself an advantageous factor for the enrichment of oligotrophic water. The orthophosphate is also the second most required nutritive element for the primary production (Berland *et al.* 1980).

These experiments of the free drifting drogue highlighted the presence of two situations when the south-west wind is dominant. The first one, the most frequent, is when the south-west wind is well established, the factory and river dilution plumes may reach the jetty and turn around it to cross a longer distance toward the north. The second one occurs when the wind is represented by south-west (SW) sea breezes and may vary in speed and direction during the day. This situation happened during hot days from end of June till September. These south-west (SW) breezes are periodic; they represent 85% of the total winds during this period and their speed can frequently exceed 5 to 6 m.s⁻¹ (Romano and Marquet 1991), as it was the case during the experiment of June 2003.

As this type of south and south – west wind is the most prevailing in Lebanon, a wide area located to the north of Selaata chemical plant might be subjected in winter and spring to strong and a balanced enrichment in both essential elements. This may create favorable conditions for the blooming of microscopic algae when environmental conditions are suitable. These ultra strong concentrations in nitrate and phosphate may also lead to the phenomenon called eutropication, but fortunately this phenomenon is quite rare to happen in this northern marine region of Lebanon according to its geomorphology as open area. Although in periods of river's dryness, like in the experiment of June, the low concentrations of nitrate with the high concentrations of phosphate will create a clearly unbalanced nutrient budget with probable deleterious consequences on pelagic and benthic ecosystems. Depending on the season, Al-Jaouz River outflow and its nitrate inputs may, or may not, partly counterbalance these massive and permanent orthophosphate inputs inside Batroun marine environment, and consequently may lead to periodic unbalanced nutrient budget in the marine waters of this coastal area. This may agree with the fact that seasonal variation of N/P ratio (Kress and Herut 2001) is mostly noticed in the euphotic zones (Cloern

2001) and that any change in the natural marine environment that may lead to a change in Redfield ratio (Redfield 1934), may be considered as a trigger for dystrophy phenomenon that causes nutritional deficit in natural population (Berland *et al.* 1980). The variation of N/P ratio in the Lebanese coastal water was shown by Abboud-Abi Saab *et al.* (2005) to take particular importance because of the irregularity and diversity of the littoral outputs.

The north wind (N) is not yearly dominant on the Lebanese coasts, but it is classified in second position in frequency. Generally this regime of wind occurs in the autumn and partly during the winter season (Anonymous 1970), and sometimes it can be well established for several days and much more violent than it was during this experiment in October 2003. The north wind appeared to play a crucial role in moving the water masses, especially the different types of factory's discharges, far to the south. The experiment of October 2003 showed that the north wind (N) of the morning, which was also the prevailing one during the previous night, triggered the movement of water masses movement towards the south (S). The orthophosphate concentrations increased gradually while the drogue was drifting southward. This increase in P-PO₄ concentrations while proceeding far from the factory to the south might be explained by the fact that under the influence of the nightly dominant north wind, the discharged masses of water impregnated with orthophosphate were rapidly dragged towards the south where they had accumulated. In the case of north wind, the impact of the Selaata's factory can be expanded and detected further to the south as it was suspected by our previous studies. Thus we consider that this type of drifted water coming from the factory can be frequent and could extend for greater distances far to the south.

The prevailing wind regime was shown to represent the detrimental impact on the dispersion of contaminants directly discharged in the marine environment of Batroun area, even when other factors were found to interfere in the displacement of water masses with spatial limitation, such as the flow intensity of the Al-Jaouz River.

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