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Linking Dinoflagellate Cyst Assemblages with Nutrient Dynamics in the Gulf of Annaba (Southwestern Mediterranean)

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ABSTRACT
This study investigates modern dinoflagellate cyst assemblages and their relationships with environmental parameters as indicators of eutrophication in the Gulf of Annaba, Algeria. In 2018, surface sediment and water samples were collected from three coastal stations, including a commercial port, to evaluate spatial variations in cyst abundance, diversity, and nutrient enrichment. A total of 874, 544 and 150 dinoflagellate cysts were recorded at stations 1 (Port), 2, and 3, respectively, reflecting strong ecological gradients linked to anthropogenic pressure and sediment characteristics. Species richness and diversity were the highest in muddy, organic-rich sediments at the port station, with dominant taxa such as *Lingulodinium machaerophorum*, *Alexandrium pacificum* indicating eutrophic conditions and potential harmful algal bloom (HAB) risks. Analyses of physico-chemical parameters indicated significantly elevated concentrations of dissolved inorganic nitrogen (DIN), phosphate (PO_4), and silicate (SiO_4) in the bottom layers, with Station 1 showing the highest values. Ammonium (NH_4) was the predominant nitrogen form, comprising over 50% of total DIN in surface and bottom waters at the port station, highlighting localized organic enrichment likely driven by urban, industrial, and port-related discharges. The distribution of dinoflagellate cysts correlates strongly with these nutrient and sedimentary patterns, validating their use as bioindicators of eutrophication. These findings underscore the ecological sensitivity of the Gulf of Annaba to anthropogenic impacts and advocate for the integration of cyst monitoring in coastal environmental.

INTRODUCTION

Environmental factors, such as temperature, salinity, nutrient availability, turbidity, and pollution, significantly influence dinoflagellate populations **(Anderson & Taylor, 1987; Frehi *et al.*, 2007; García-Moreiras *et al.*, 2021)**. Under adverse conditions, many species enter a dormant state by encysting **(Deng *et al.*, 2025)**. Dinoflagellate cysts settle into sediments and preserve the history of the dinoflagellates in the water column **(Dale, 1976; Reid & Harland, 1978; Xillovich *et al.*, 2025)**.

Approximately 200 marine dinoflagellate species develop resting cysts as part of their life cycle **(Head, 1996)**. These cysts can thrive in sediments for a duration of several years **(Dale, 2001)** and even up to a hundred years **(Ribeiro *et al.*, 2011)**.

Encystment is also a survival strategy of the dinoflagellates in times of unfavorable conditions. Further, cysts also act as an area's seed bank, which can initiate new algal blooms when the right conditions prevail **(Dale, 1983; Lewis *et al.*, 1999)**. Studies of cysts can therefore provide early indications of the presence of toxic species or imminent possibilities for future toxic blooms, even revealing as yet undetected species present in the water column **(Anderson *et al.*, 1982; Ellegaard *et al.*, 1993; Nehring, 1993; Hazem & Khammar, 2025)**.

Although a world ocean atlas of cyst distribution studies suggests that there is a great deal of information available **(Draredja *et al.*, 2020; Rodrigues *et al.*, 2022)**, limited research on Algerian subcontinent dinoflagellate cysts exists. Several studies in the distribution of dinoflagellates and how they affect the marine ecosystem have been conducted in the northeast of Algeria **(Frehi *et al.*, 2007; Hadjadji *et al.*, 2020)**.

According to **Hadjadji *et al.* (2014)**, **Cheniti *et al.* (2018)** and **Hazem and Khammar (2025)**, the Algerian coasts receive large volumes of ballast water from extensive maritime traffic. This ballast water serves as a vector for harmful dinoflagellate species, posing risks to both public health and aquaculture **(Brante *et al.*, 2025)**. Within the Gulf of Annaba, a part of the southwestern Mediterranean, some of the dinoflagellate species have been responsible for recurring blooms that tint waters, and some of these are potentially toxic **(Hazem & Khammar, 2025)**. There is no published work yet, however, on current dinoflagellate cyst assemblages and distributions within this region.

The main aim of this study is to explain the present assemblages of dinoflagellate cysts in the Annaba Gulf surface sediments. Specifically, with focus on cyst morphology, the current study aims at establishing connections between the cysts in the sediments and their corresponding mobile species in the water column. In addition, the research seeks to explore the effect of port activity on the cysts collected at the Annaba Port.

MATERIALS AND METHODS

1. The study area

The Gulf of Annaba, located in the far east of Algeria, is bounded by Cape Rosa to the east (8° 15' E, 36° 68' N) and Cape Garde to the west (7° 16' E, 36° 38' N). It has a maximum depth of 70m and features isobaths ranging from 3 to 28m. Notably, these isobaths are more widely spaced in the south and closer together in the north. The dominant currents, flowing eastward along the southeastern coast of Cape Garde, are influenced by swells originating primarily from the northwest and east-northeast. Furthermore, the gulf is fed by two main rivers, the Mafragh and the Seybouse, whose discharge varies significantly with the seasons **(Amira, 2018, Ounissi *et al.*, 2018, 2021)**. Consequently, these rivers transport significant amounts of mineral and organic matter from agricultural, domestic, and industrial sources **(Amira, 2018; Ziouch *et al.*, 2022; Boukef, 2025)**. In addition, the gulf receives urban discharges and industrial effluents from coastal facilities, particularly the FERTIAL plant and the phosphate factory located near the port **(Boukef, 2025)**. The gulf also hosts Algeria's second most important industrial and commercial port, which is accessible to international traffic. The study area encompasses Annaba Bay, located between the Seybouse River to the south and Cape Garde to the west. This area is characterized by a narrow and rugged continental shelf that gradually widens offshore. To achieve this work, three sampled sites were selected:

Station S1 is located at 36°54.325′N, 7°46.716′E, and -14.5m in depth. The sediment is a fine-grained mud with a very high fine fraction (Pf: 98.4%), indicating a low-energy depositional environment favorable for the settling of organic matter and cysts (Table 1) (Fig. 1). This station illustrates the sheltered nearshore zone with very minor hydrodynamic disturbance.

Fig. 1. Study area and location of sampling stations S1, S2, S3.

Station S2 is at 36°54.033′N, 7°46.833′E, at the relatively shallower depth of -10.5 meters. Sediment here is also mostly mud (Pf: 93.6%), but with a somewhat higher coarse fraction (Pg: 6.42%) than at S1. It is an intermediate zone, still under the influence of nearshore processes but potentially subject to occasional resuspension events. Station

S3 (36°54.792′N, 7°47.162′E) is at the deepest depth sampled (-20 meters). The sediment is mud-sand with a significantly lower fine content (Pf: 73.1%) and higher coarse fraction (Pg: 26.9%). It is an offshore station, in an environment exposed to higher hydrodynamics and coarser sediment deposition, reflecting a transition to high-energy environments (Table 1) (Fig. 1).

2. Sediment sampling

Surface sediments were collected in October 2018 from the three selected stations (Fig. 1) characterized by sandy-mud to muddy bottoms (Fig. 1). Samples were obtained using an Ekman grab at depths ranging from 10 to 30 meters, then transferred to plastic containers and stored in the dark at 4°C.

The extraction of dinoflagellate cysts was performed following the method described by **Lacasse and Rochon (2013)**, which involves wet sieving using water without the use of acids. Using a spatula, the surface layer of each sediment sample was homogenized, and 1cm³ subsample was collected by displacing an equal volume of filtered seawater in a graduated cylinder. To deflocculate the sediments, the subsamples were subjected to an ultrasonic bath (VWR International model SOT) for two minutes, following the procedure of **Matsuoka and Fukuyo (2000)**.

Samples were then sieved through Nytex membranes of 100 and 20µm using 0.45µm filtered seawater. The coarse fraction (>100µm) was discarded, while the 20–100µm fraction was retained and transferred to a 50ml beaker using a wash bottle. Fine particles were suspended and concentrated through gentle rotary motion. The resulting supernatant was poured onto a 20µm Nytex membrane and transferred into a 60 x 15mm Petri dish (Fisherbrand). The 20– 100µm fraction was then examined under an inverted microscope (Nikon Eclipse TE2000-U) at magnifications ranging from 10x to 40x.

3. The terminology used to describe dinoflagellate

Cysts terminology and description was based primarily on the research conducted by **Rochon *et al.* (1999)**, **Matsuoka and Fukuyo (2000)**, **Head *et al.* (2001)**, **Marret and Zonneveld (2003)**, **Matsuoka *et al.* (2009)**, **Zonneveld and Pospelova (2015)**, **Van Nieuwenhove *et al.* (2016)** and **Gurdebeke *et al.* (2020)**.

4. Granulometric analysis

The particle size of the sediment was determined using the sedimentary method in accordance with the standards NF P 94-057 and XP CEN ISO/TS 17892-4. A sub-sample of approximately 50g of dry sediment was first taken for analysis. Organic matter and other impurities were removed by treating the sample with hydrogen peroxide (H_2O_2). The sample was then dispersed in a solution of sodium hexametaphosphate $(NaPO_3)_6$ to prevent particle aggregation.

The sediment suspension was transferred into a sedimentation column of known volume, and the sedimentation process was monitored over a specified period. Particle sizes were determined based on their settling velocities, according to Stokes' Law, which relates the size of the particles to their rate of sedimentation. The fractions of particles smaller than 63µm were analyzed by this method, while larger fractions were separated by wet sieving.

Data from the sedimentation process were used to construct a granulometric profile for each sample, providing information on the distribution of particle sizes within the sediment (Table 1).

5. Physicochemical water analysis

Surface water samples from the three stations were collected for nutrient analysis in 1.5L plastic bottles and processed in the same day. In addition to these samples, bottom water samples were collected using a Niskin bottle. In the laboratory, the samples were filtered through Whatman GF/C glass fiber filters (0.45 µm porosity). Nitrite (NO_2), nitrate (NO_3), ammonium (NH_4), phosphate (PO_4) and silicate (SiO_4) concentrations were determined according to the methods described by **Parsons *et al*. (1989)**.

Simultaneously, on-site measurements of temperature, salinity, pH, and dissolved oxygen (O_2) were performed with a HANNA HI9828 multiparameter device.

6. Statistical analyses

Significant differences in sediment property among the three sites were established by one-way analysis of variance (ANOVA). Data were first subjected to normality test (Shapiro-Wilk test) and test for equality of variances (Levene's test) prior to analysis. Where the differences were significant ($P < 0.05$). Statistical analysis was conducted utilizing R software R-4.5.1

RESULTS

1. Physical and chemical properties of the sampling stations

The primary objective of this study was to identify the cysts found in sediment samples taken from three different stations, which are subject to various sources of pollution **(Triki *et al.*, 2017)**. It is necessary to consider the function and dynamics of the marine ecosystem, moreover it is empirical to identify whether it has biotic or abiotic factors. Indeed, physical parameters play an important role in the evaluation of the studied environment **(Tavakoly Sany *et al.*, 2018; Birch, 2023)**.

The mean surface temperature is approximately 21.0°C. At the bottom, the temperature decreased to around 17.00°C at the three studied stations (Fig. 2). During winter, the temperature varied between 13 & 16°C at the bottom and surface, respectively, (Fig. 2). In contrast, during the summer period, the surface temperature reached 26°C at the three sampled stations. However, at the bottom, the three stations showed different temperatures (St1: 20°C, St2: 21°C, St3: 23°C) (Fig. 2).

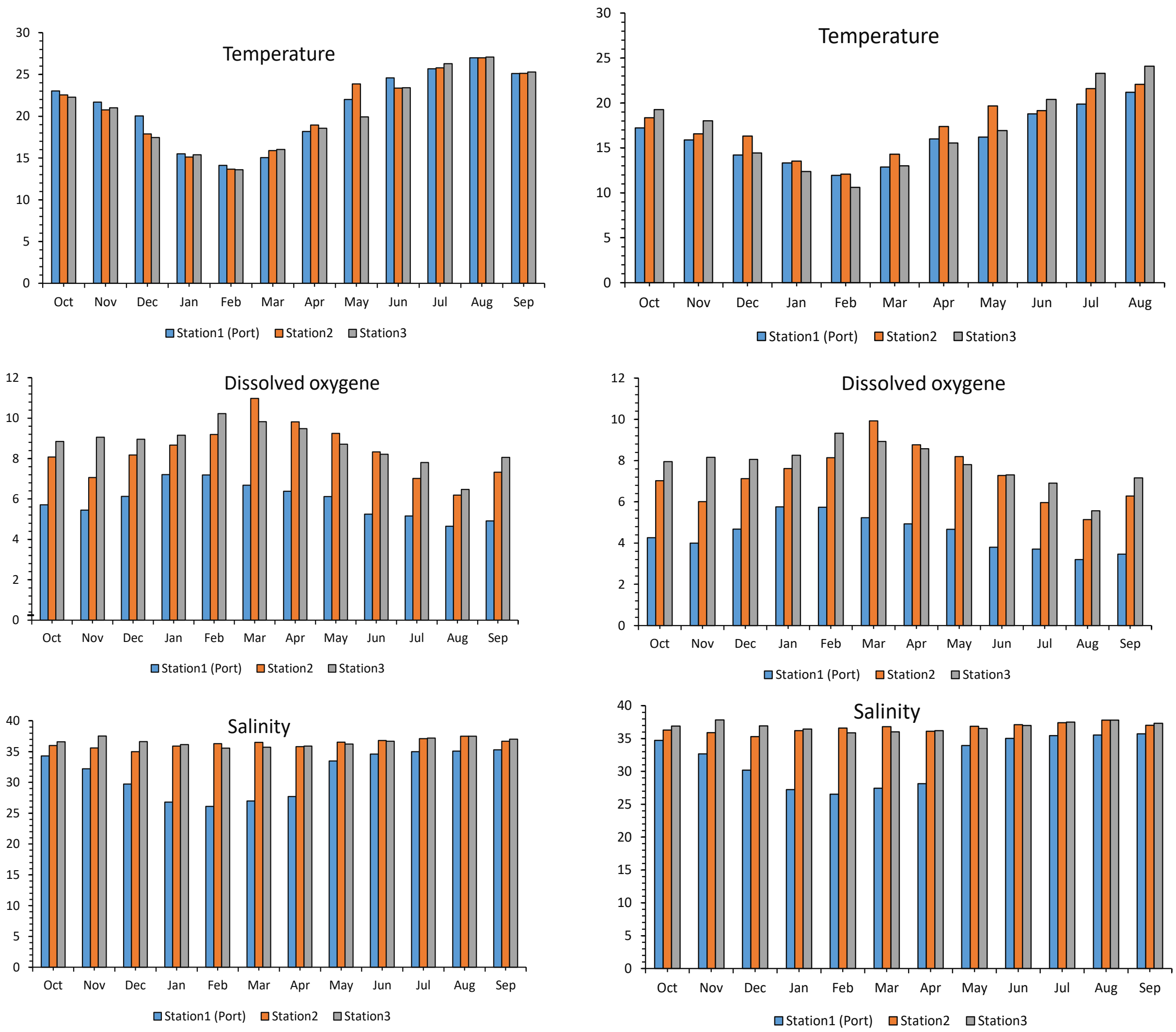

Fig. 2. Variations of physical parameters at the three studied station during the year 2018

These seasonal and spatial temperature variations are consistent with previous findings in the western Mediterranean and Algerian Basin, where summer stratification and surface heating are known to drive significant vertical thermal gradients **(Béthoux, 1980; Millot, 1999; Puillat *et al.*, 2006)**. Based on data depicted in Fig. (3), no significant differences could be observed between the stations, with *P*-values of 0.65 and 0.97 indicating a lack of statistical significance.

Similarly, salinity exhibited a comparable pattern of fluctuation between the surface and the bottom (Fig. 2). Specifically, the station with the lowest salinity (32 PSU) is the port station, whereas the two stations with the highest salinity are the two remaining stations (37 PSU) (Fig. 2). According to data in Fig. (3), a significant difference was detected between the port station and the two other stations. This reduced salinity at the port station can likely be attributed to freshwater input from river discharge, urban runoff, or limited water exchange with open sea areas. Indeed, such conditions are typical for semi-enclosed or anthropogenically influenced coastal zones.

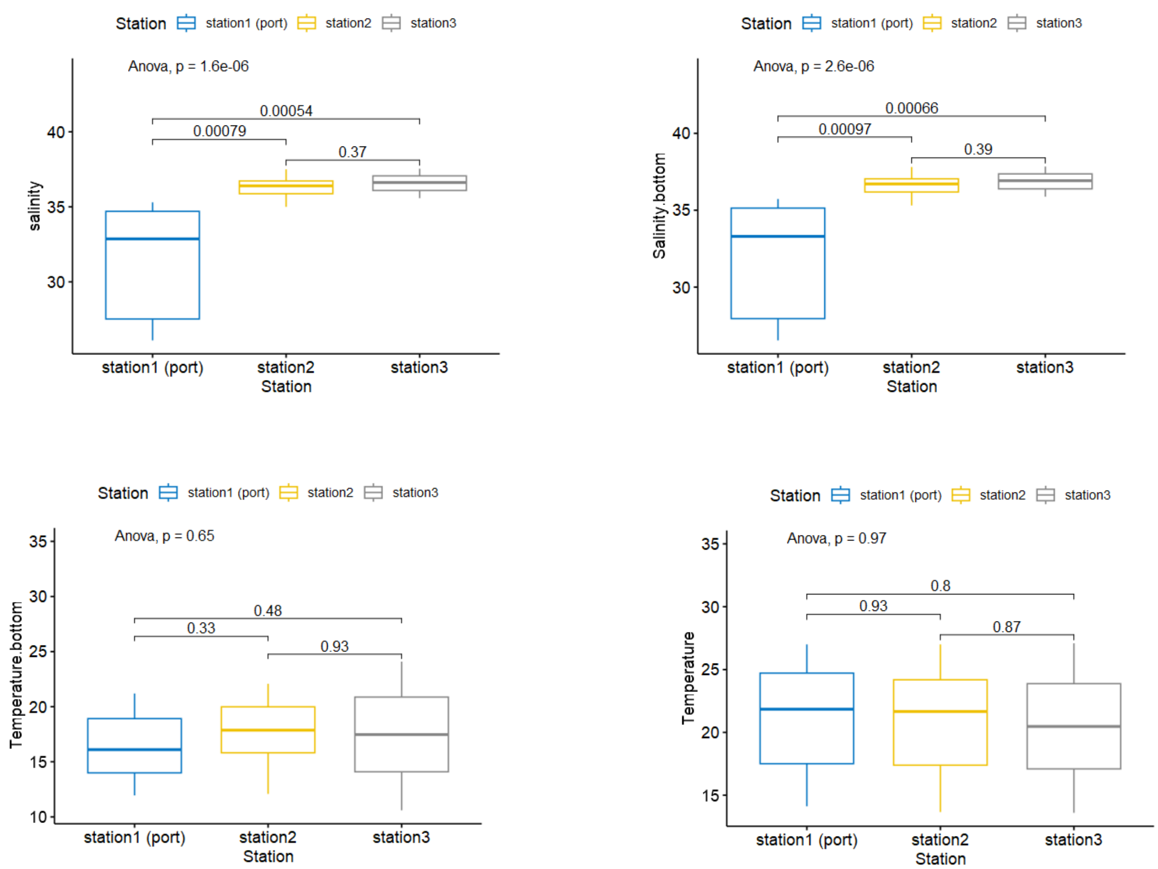

Fig. 3. The ANOVA test realized at the three sampled stations for the physical parameters

This pattern is consistent with previous findings in similar nearshore and port environments along the Algerian coast, where freshwater inputs and restricted circulation result in reduced salinity compared to open marine waters **(Millot, 1999; Sammari *et al.*, 1999)**. Moreover, salinity gradients between coastal and offshore waters are well-documented in the Algerian Basin, particularly in areas affected by human activity or freshwater inflow **(Béthoux, 2002; Puillat *et al.*, 2006)**.

Dissolved oxygen (DO) concentrations showed significant differences between the surface and the bottom (Fig. 2). Among the three stations, the port station (St 1) exhibited the lowest oxygen levels, with values of 5.9mg L^{-1} at the surface and 4.5mg L^{-1} at the bottom (Fig. 2).

This reduced DO level at the port can likely be attributed to several factors, including limited water circulation, a higher organic matter load from urban or industrial discharges, and microbial degradation processes that consume oxygen conditions often observed in semi-enclosed coastal environments.

Indeed, similar patterns have been reported in Algerian coastal zones, where anthropogenic influence and eutrophication tend to decrease oxygen availability, especially near port areas and estuaries **(Boudjellal *et al.*, 2015; Rouabhi *et al.*, 2019)**.

Furthermore, stratification during warmer months can further reduce oxygen exchange between surface and bottom layers, contributing to hypoxic conditions near the seabed **(Millot, 1999; Puillat *et al.*, 2006)**.

Dissolved nutrients play a crucial role in the stability of the marine ecosystem **(Rijal, 2025)**. The concentration of dissolved inorganic nitrogen (DIN) shows different levels between stations and depths (Fig. 4). Specifically, the port station presents a high concentration of DIN, with 7.9 and 12.1mg L^{-1} in the surface and the bottom, respectively (Fig. 4). In contrast, the two other stations were less rich than station 1. These elevated levels are likely linked to anthropogenic inputs such as domestic sewage, industrial discharges, and urban runoff, which are commonly observed near port areas and semi-enclosed coastal environments. Indeed, in Algerian coastal waters, especially near urbanized or industrial zones, similar DIN enrichment has been reported, often associated with eutrophication risks and oxygen depletion in bottom layers **(Boudjellal *et al.*, 2015; Tabet *et al.*, 2018)**. Furthermore, the accumulation of nutrients at the bottom can also result from sediment regeneration and reduced vertical mixing, particularly during warmer months when water column stratification is stronger **(Millot, 1999; Puillat *et al.*, 2006)**.

DIN levels fluctuated between 4.1 and 3.7mg L^{-1} in the surface waters of St 2 and St 3, respectively. However, in contrast to the surface, DIN concentrations increased by approximately 1.4-fold at St 2 and 1.2-fold in St 3 at the bottom (Fig. 4). Within the DIN pool, NH_4 dominates, comprising about 52% at St 1, 37-35% at St 2, and 39-41% at St 3 surface and bottom waters, respectively.

For the NO_3 form, its proportion varied between 38.65 and 47.30% in the surface and between 43.04 and 47.35% in the bottom for the 3 studied stations.

Overall, the obtained results showed that the port station (St 1) contained more nitrogen than the other two stations.

The elevated concentrations of total DIN and the dominance of ammonium at the port station can be attributed to localized anthropogenic sources, including wastewater discharge, port-related industrial activity, and limited flushing capacity.

Eminently, ammonium is often the predominant nitrogen form in areas receiving untreated or partially treated effluents due to its association with organic waste decomposition and microbial activity **(Boudjellal *et al.*, 2015)**.

Consequently, similar distributions of nitrogen species have been reported along urbanized parts of the Algerian coast, where ammonium tends to dominate in nearshore waters, particularly in port environments and semi-enclosed bays **(Taleb *et al.*, 2016; Tabet *et al.*, 2018; Bensalem *et al.*, 2021)**. Furthermore, comparable trends have also been observed in other regions of the Mediterranean, where ammonium enrichment and DIN accumulation are linked to anthropogenic pressures and weak hydrodynamics in coastal systems **(Sanchez-Garrido *et al.*, 2013)**. Additionally, nitrate fractions tend to increase with depth due to nitrification processes and sedimentary fluxes, especially in stratified and low-oxygen bottom waters **(Millot, 1999; Puillat *et al.*, 2006; Socal *et al.*, 2008)**.

The NH_4 concentration at the St 1 surface was 4.18mg L^{-1} (Fig. 4). This concentration increased by 1.5 fold in the bottom (6.16mg L^{-1}). The same tendency between the surface and the bottom was recorded for the St 2 and St 3 with the increase of the concentration from 1.5 to 2mg L^{-1} for St 2 and from 1.5 to 1.8mg L^{-1} (Fig. 4).

The higher ammonium concentrations in the bottom waters, especially at the port station, may be attributed to the accumulation and decomposition of organic matter under low oxygen conditions, which enhances ammonification.

Port zones typically receive significant nutrient loading from urban runoff, sewage, and industrial discharges, leading to elevated ammonium (NH_4) levels especially in benthic layers where organic material settles and undergoes microbial breakdown **(Boudjellal *et al.*, 2015)**. Furthermore, limited water exchange and stratification can prevent vertical mixing, allowing ammonium to accumulate in bottom waters **(Millot, 1999; Puillat *et al.*, 2006)**.

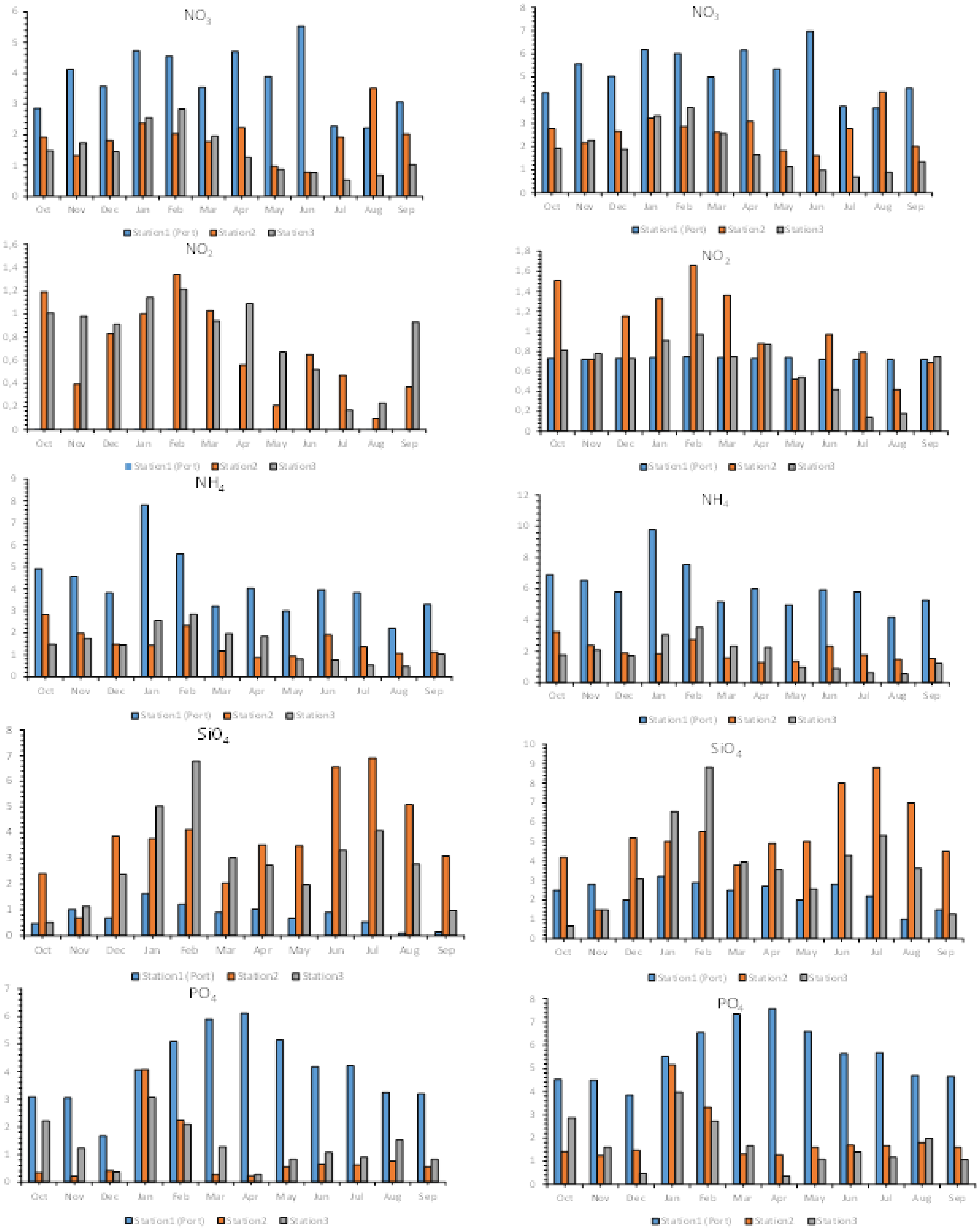

Fig. 4. Variations of dissolved nutrients at the three studied station during the year 2018

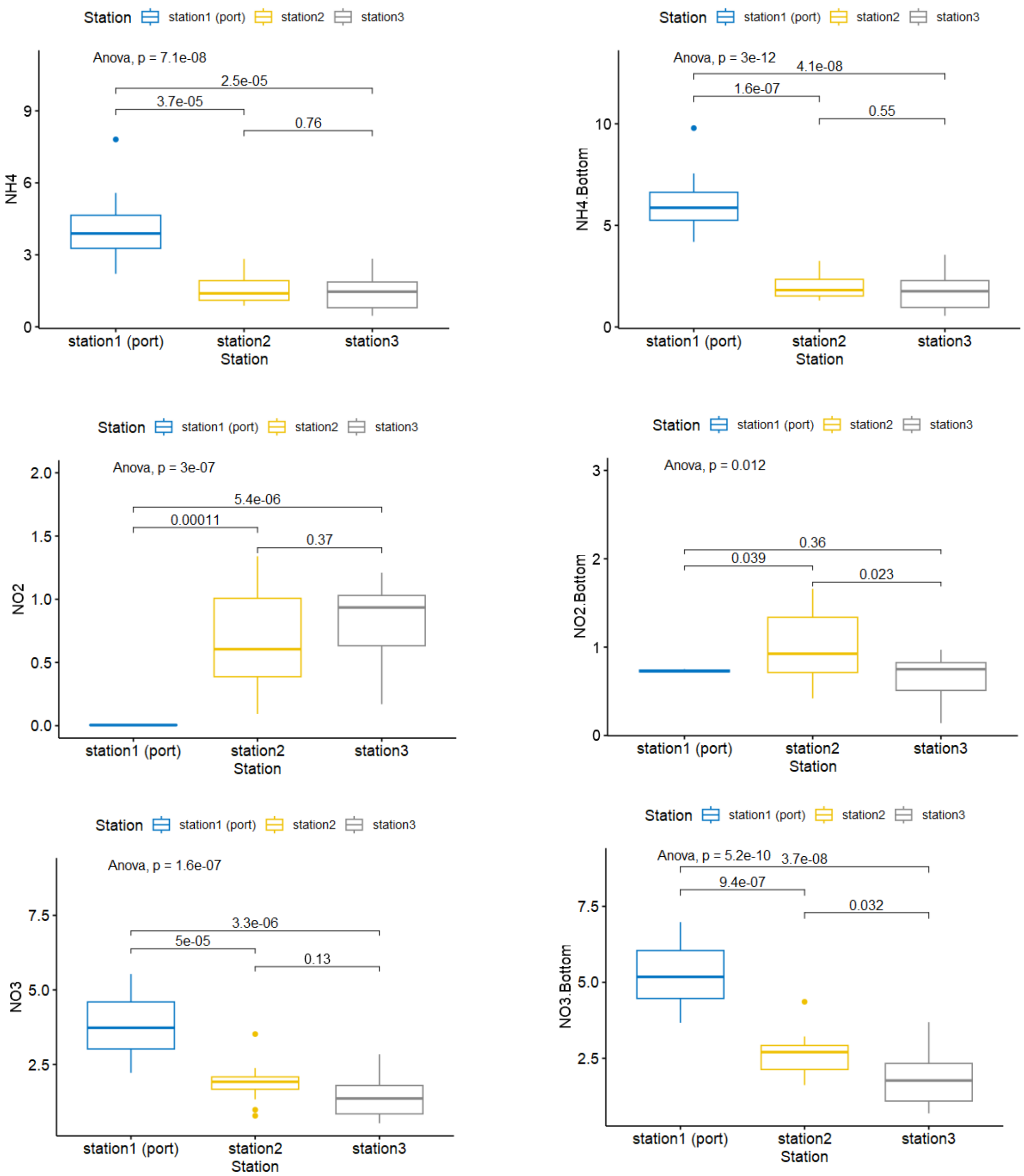

Fig. 5. The ANOVA test performed on the three sampled stations for dissolved nitrogen forms

Consequently, these findings align with previous studies along the Algerian coast, where ammonium was found to dominate the nitrogen pool in nutrient-enriched and poorly flushed areas **(Taleb *et al.*, 2016: Tabet *et al.*, 2018; Bensalem *et al.*, 2021)**.

Moreover, similar patterns have been observed across other parts of the Mediterranean, where semi-enclosed systems such as lagoons and ports experience high ammonium concentrations due to reduced circulation and strong anthropogenic influence **(Socal *et al.*, 2008; Sanchez-Garrido *et al.*, 2013)**.

Similar to NH_4, high concentrations of NO_3 were recorded in the bottom waters, with 5.21, 2.66, and 1.86mg L^{-1} for St 1, St 2, and St 3, respectively (Fig. 5). However, these levels decreased by approximately 1.3-fold in the surface waters for the three sampled stations. Among the DIN pool, NO_2 represents the minor form (Fig. 5). Consistent with the other forms of DIN, the highest levels of NO_2 were recorded in the bottom waters, with 0.73, 1.00, and 0.65mg L^{-1} for St 1, St 2, and St 3, respectively (Fig. 5). According to Fig. (5), there were significant differences among the sampled stations in the concentrations of the various nitrogen forms, with the most pronounced differences observed in nitrate and ammonium levels.The higher nitrate concentrations at the port station (St 1) further indicate localized anthropogenic input, such as wastewater discharge and organic enrichment from port activities **(Boudjellal *et al.*, 2015; Tabet *et al.*, 2018)**.

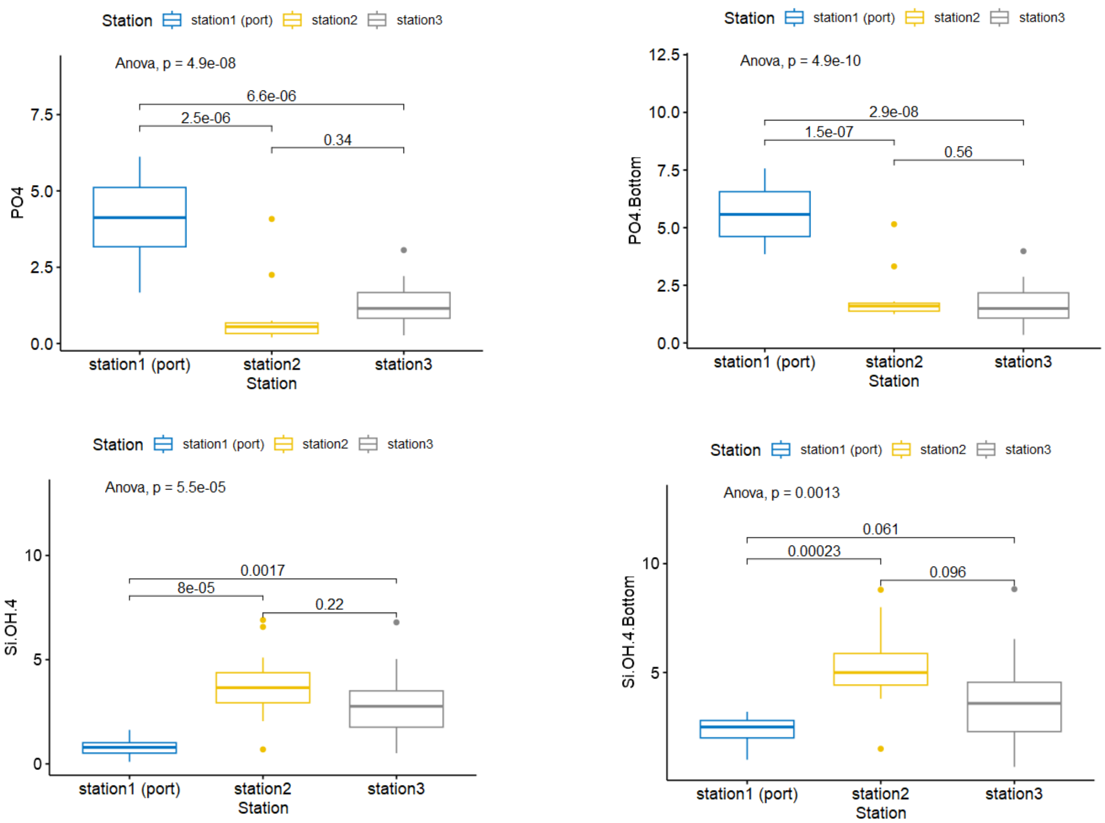

Fig. 6. The ANOVA test realized in the three sampled stations for phosphate and silicic acid forms.

Among the dissolved inorganic nitrogen (DIN) forms, nitrite (NO_2) was the least abundant (Fig. 4). Nevertheless, like the other forms, the highest nitrite levels were also found in the bottom waters, with concentrations of 0.73mg L^{-1} at St 1, 1.00mg L^{-1} at St 2, and 0.65mg L^{-1} at St 3.

Elevated nitrite in the bottom waters may result from incomplete nitrification or denitrification processes under low-oxygen conditions, which are common in stratified and organic-rich coastal environments **(Millot, 1999; Puillat *et al.*, 2006)**. Consequently, such accumulation is consistent with findings in eutrophic or semi-enclosed Algerian coastal waters, where nutrient cycling is strongly influenced by sediment-water interactions and anthropogenic nutrient loading **(Taleb *et al.*, 2016; Tabet *et al.*, 2018)**. As another form of dissolved inorganic nutrients (DIN), phosphate (PO_4) plays a crucial role in aquatic ecosystems (**Dai *et al.*, 2025**).

As shown in Fig. (4), high levels of PO_4 were recorded in the bottom waters, with concentrations of 5.60, 1.96, and 1.70mg L^{-1} at St 1, St 2, and St 3, respectively. These levels represent an increase of 1.30mg L^{-1} at St 1 and St 3, and 2.16 mg L^{-1} at St 2. These elevated concentrations may indicate nutrient enrichment and potential anthropogenic influence, consistent with findings in other Mediterranean and Algerian coastal regions **(Bouaziz *et al.*, 2020)**.

The SiO_4 is a key element for phytoplankton growth, especially for diatoms. The SiO_4 concentrations exhibited similar fluctuations to the other elements, with high concentrations in the bottom waters and low concentrations in the surface waters (Fig. 4). Specifically, the highest levels were noted in the bottom waters: 2.34, 5.28, and 3.76mg L^{-1} (Fig. 4). However, these concentrations decreased by approximately 3.03-fold for St 1 and 1.3-fold for St 2 and St 3 in the surface waters. This vertical distribution is consistent with studies from the Algerian and broader Mediterranean coasts, where bottom enrichment of silicate is attributed to sediment interactions and reduced uptake by surface-dwelling organisms **(Boudiaf *et al.*, 2021)**.
Given to data in Fig. (6), a significante difference was recorded between sites.

2. Cyst concentration and rate as a function of sediment depth and grain size

The data from the three coastal stations along the Algerian Mediterranean coast reveal significant spatial variation in environmental conditions and biological responses. Station 1, located at the port and characterized by fine muddy sediments, exhibited the highest organic matter content (22.93%) and water content (79.59%) (Table 1). These conditions supported a rich dinoflagellate community, as reflected by the highest total cyst count (874), cyst concentration (1652.17 cysts/g dry sediment), and species diversity index (31). Station 2 also had muddy sediments with slightly lower organic matter (22.28%) and water content (75.71%) (Table 1). It showed a moderate biological response, with 544 total cysts, a cyst concentration of 839.50 cysts/g, and a species diversity of 29. In contrast, Station 3 had mixed mud-sand sediments and showed signs of environmental stress, with the lowest organic matter (18.62%), water content (63.86%), and significantly reduced biological indicators only 150 cysts, a cyst concentration of 299.40 cysts/g, and the lowest species diversity (17) (Table 1).

Table 1. The characteristics of the sampling stations with nature of bottom, water depth (m), relative proportion **(%)** of sediment grain size, water content **(%)**, organic matter **(%)**, total number of resting cysts/cm^3, cyst concentration (cysts g-I of dry sed) and diversity

Site	Sediment	Depth m	Pf (%)	Pg (%)	Water (%)	M0 (%)	Cyst/cm^3	Concentration cyst/g de sed	Diversity
S1	Mud	-14.5	98.4	1.63	79.6	22.9	874	1652.17	31
S 2	Mud	-10.5	93.6	6.42	75.7	22.3	544	839.50	29
S 3	Mud-sand	-20	73.1	26.9	63.8	18,6	150	299.40	17

3. Species abundance and diversity

Station 1 shows the highest total abundance with 874 individuals, indicating it may be a biologically richer or more productive zone. The abundance decrease to 544 individuals, suggesting moderate ecological conditions at Station 2. In addition, Station 3 shows significantly lower abundance at 150 individuals, which could reflect environmental stress and lower nutrient availability. This spatial distribution could be linked to environmental gradients such as nutrient concentration, sediment type, hydrodynamics, or anthropogenic pressures. Similar patterns were observed along the Algerian coast where nutrient enrichment due to terrestrial runoff led to higher benthic and planktonic organism abundance nearshore **(Bouaziz *et al.*, 2020; Boudiaf *et al.*, 2021)**.

Table (2) highlights notable spatial variation in species abundance and diversity among the three sampling stations along the studied coastal zone.

Lingulodinium machaerophorum is highly dominant at St 1 (417 individuals), representing nearly half of the total abundance. This species is a known bioindicator of eutrophic conditions and warm, nutrient-rich environments. *Alexandrium pacificum* is present across all stations with relatively high values, particularly at St 1 and St 2. This dinoflagellate is potentially toxic and commonly found in Mediterranean waters under favorable nutrient conditions. First reported as *Alexandrium catenella* by **Frehi *et al.*** (**2007**), following a bloom observed in March 2002 in Annaba Bay, the species was identified based on morphological criteria. However, this identification was revised by **Hadjadji *et al.*** (**2020**), who conducted a molecular analysis (ribotyping and sequencing of the LSU rDNA gene) using cysts collected from the same areas. Their results showed that the species in question actually belongs to group IV of the *Alexandrium tamarense* complex, now recognized as *Alexandrium pacificum* (plate. 1.5). *Selenopemphix quanta*, *Polykrikos kofoidii* and *Protoperidinium nudum* (plate. 1.1, 1.4. 1.6) also show higher values at Station 1, reinforcing the idea of a more dynamic or nutrient-enhanced habitat.

The greater diversity and abundance at St1 suggest a more availability of nutrients. However, high abundance of some species like *Lingulodinium machaerophorum* (plate. 1.3) and *Alexandrium pacificum* (plate. 1.5) may also indicate eutrophication, which can shift the community structure.

Stations 2 and 3, particularly St3, with lower total abundance and fewer taxa, may be influenced by pollution, hydrological stress, or sediment conditions that limit species proliferation.

Table 2. Spatial variation in species abundance and diversity at the three sampling sites

Cysts	Station1	Station 2	Station3
Ling mach	417	174	32
Scrippsiella acuminata	140	57	17
Quin conc	16	11	7
Scrip troch	74	37	11
Alex min	86	76	28
Poly schwa	37	9	3
Poly kof	40	13	6
Sellen neph	4	17	8
Proto nud	40	14	
Vota spin	5	3	
Spini delli	50	21	6
Spini mira	3	5	
Leuje sab	4	7	6
Dubri caper	1		2
Proto stell	2	1	
Penta dalei	1	7	
selen quanta	29	27	9
Vota calvum	2	3	
Proto amer	16	9	7
Brig simp	8	13	4
B. caria	2	7	
S. hypercan	6	4	
R brun lisse	3		3
R brun épin	4		2
scri crista	9	13	
spi bentorii		3	
***echinidi* sp.**	3	11	
islan minut	5	5	

Trinov appla	2	3	
R.épineux	5	7	
***Alex* sp.**	13	27	14
***Diplopsalis* sp.**	2	3	
oper nud	6	14	2
Total	**874**	**544**	**150**
Total taxon number	**31**	**28**	**17**

Plate 1 illustrates the dinoflagellate cysts derived from recent sediments of Annaba Bay in the western Mediterranean. The microscopic images display the most abundant cyst species across the three studied stations: *Selenopemphix quanta*, *Scrippsiella acuminata*, *Lingulodinium machaerophorum, Polykrikos kofoidii*, *Alexandrium pacificum,* and *Protoperidinium nudum.*

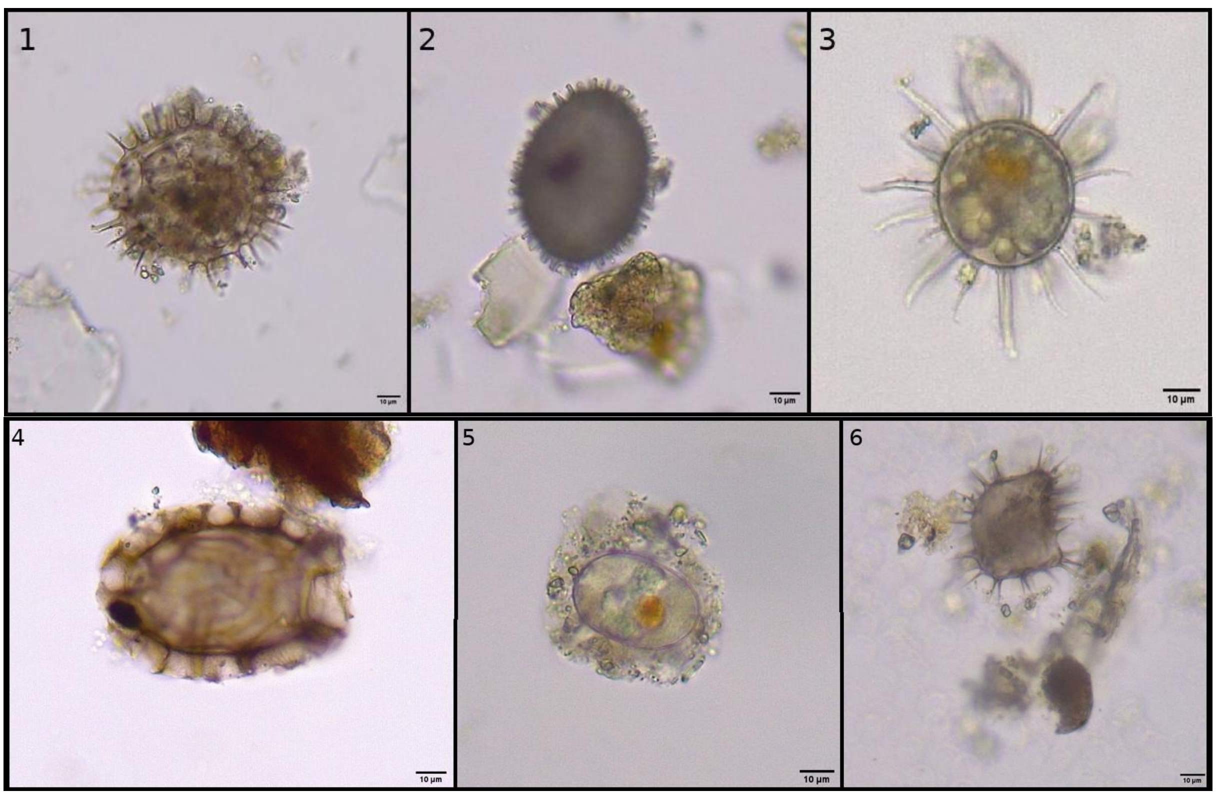

Plate 1. Dinoflagellate cysts from recent sediments of Annaba Bay, western Mediterranean – Light microscopy images: 1- *Selenopemphix quanta*; 2- *Scrippsiella acuminate* ; 3- *Lingulodinium machaerophorum;* 4- *Polykrikos kofoidii*; 5- *Alexandrium pacificum*; 6- *Protoperidinium nudum*. Scale bar 10 µm

These patterns align with observations from the Gulf of Annaba and the Oran Bay (Algerian coast), where spatial differences in phytoplankton and benthic invertebrate communities were linked to variations in water quality, nutrient availability, and human impact **(Taleb *et al*., 2016)**.

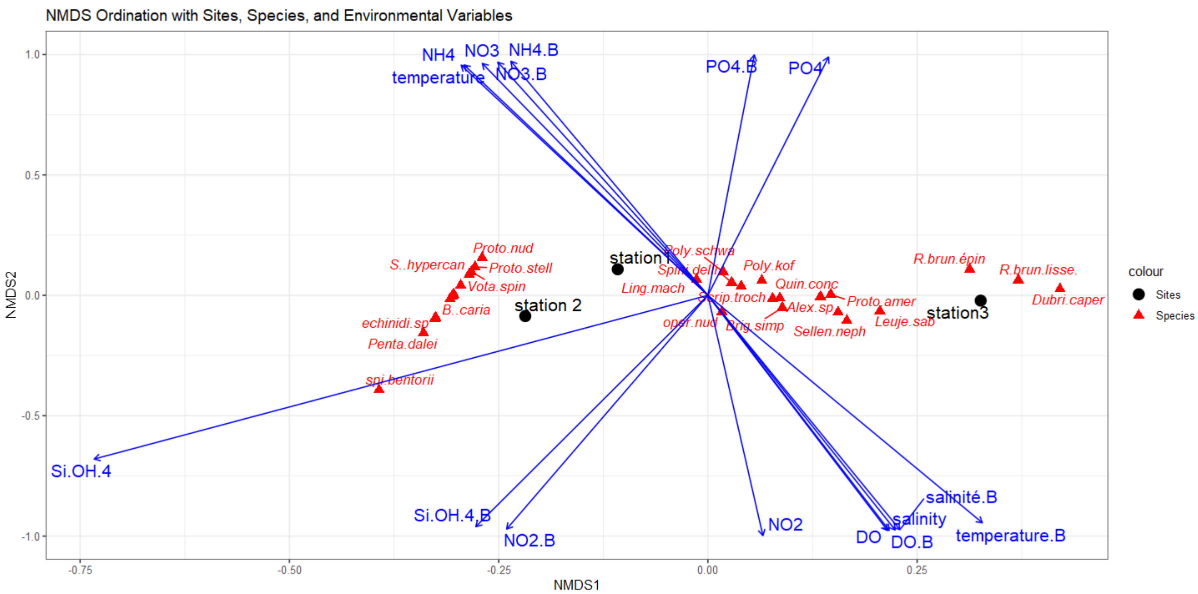

Fig. 7. Principal component analysis (PCA) of cysts communities of Annaba Bay in relation to abiotic factors

CONCLUSION

Principal component analysis (PCA) (Fig. 7) of dinoflagellate cyst assemblages in the Gulf of Annaba reveals significant ecological impacts from anthropogenic activities. A clear relationship exists between nutrient enrichment (DIN, ammonium) and dinoflagellate community composition, with the heavily impacted port station exhibiting the highest cyst abundance and eutrophication indicating species. Dinoflagellate cysts are thus valuable bioindicators for coastal water quality assessment. The observed stratification and hypoxia emphasize the need for integrated coastal management to mitigate eutrophication and harmful algal blooms in the Gulf of Annaba.

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