

PHYTO-ZOOPLANKTON COUPLING OFF ALEXANDRIA (EGYPT)

Wagdy Labib

National Institute of Oceanography & Fisheries, Kayet Bey,
Alexandria, Egypt

key words: Phyto-Zooplankton variability, interaction, neritic waters, Alexandria .

ABSTRACT

Based on short-term sampling collection in the neritic waters off Alexandria (Egypt), diatoms contributed recurrent intensive occurrence most of the time, while the microflagellates *Micromonas* and *Pyramimonas* species appeared in the transient periods (October and May). Zooplankton exhibited several peaks in early and late September, mid-January and early August, mainly copepods and protozoan species. Phyto-zooplankton abundance was affected by multi-factorial control with temperature and salinity being the majors, and nitrate at some time.

Zooplankton grazing has been postulated to play at times an effective role in regulating the phytoplankton cycle, and inflicts losses on its numerical standing crop. Yet, their large continuous seasonal variations had strongly influenced the phyto-zooplankton relationship. Subsequently, different patterns could be distinguished: top-bottom (inverse) relationship at intermittent periods when diatoms dominated; reduced grazing pressure connected with specific diatom species (*Asterionella glacialis*, *Chaetoceros* spp., *Rhizosolenia delicatula*); and/or with mixed community of diatom, dinoflagellate and euglenophyte species; inability of grazing to control blooms of the fast-growing diatoms (*Cylindrotheca closterium*, *Thalassiosira* spp.), and that of microflagellates of mono-specific nature (*Pyramimonas* spp.); positive increasing relationship with small-sized cells (*Skeletonema costatum*, *Thalassiosira* spp.); and a time lag (massive zooplankton occurrence followed that of phytoplankton within a week during August and September). Zooplankton grazing pressure could help the change in phytoplankton dominance and composition (the possible avoidance of zooplankton consumers to take up the non-diatom cells as long as the smaller

producers *T. subtilis*, *T. pseudonana* and *S. costatum* were present, offering some advantage to non-diatom species to dominate).

INTRODUCTION

In sheltered estuaries and shallow coastal waters subject to a massive source of nutrient inflow, the large temporal and spatial variations in primary production, phytoplankton abundance, blooms, succession and chlorophyll *a* concentrations could be attributed to a diverse set of physical-chemical and biological processes (Pennock and Sharp, 1994), which are considered crucial factors in determination the structure of the pelagic foodweb in an area (Colijn, 1998).

Plankton in temperate bays is highly variable and recurrent seasonal blooms are documented, with a possible shift in the phytoplankton community structure (Smayda, 1990). Such systems, affected by nutrient-rich land run-off, with different patterns of concentrations and variability (Justic *et al.*, 1995) rendered the establishment of definite cause-effect relationship a difficult task (Harding, 1994).

Zooplankton assemblage appears to be closely related to the environmental changes that occur regularly in the water column, such as surface heating, cooling, stratification, mixing, and phytoplankton blooms, community structure (Verheye *et al.*, 1998), and other processes as benthic grazing (Officer *et al.*, 1982), abundance of small pelagic fishes (Lluch-Belda *et al.*, 1989), and the importance of the relative densities of predator and prey (Carpenter and Kitchell, 1993).

Phyto-zooplankton relationship received a rather limited attention in Alexandria waters. Monthly sampling collection was carried out in the Eastern Harbour, a semi-enclosed marine basin, from August 1986 to July 1987 (Aboul-Ezz and Zaghoul, 1990). The authors reported two major phytoplankton peaks in October 1986 (*Cyclotella meneghiniana*, the causative species) and May 1987 (*Alexandrium minutum*), and a minor peak in March (*Amphichrysis compressa* and *Chaetoceros affinis*), while the zooplankton population gained its peaks in August (Rotifers, *Brachionus* spp.), February and April (*Pedalia* sp. and *Tintinnopsis companula*, respectively). Generally, an inverse phyto-zooplankton relationship was found.

The present study based on short-term sampling collection is therefore the first trial in the neritic waters off Alexandria to assess

the alternation in phytoplankton and zooplankton abundance, community structure and species composition in relation to the variability of environmental characteristics, which could help to highlight possible controlling factors. This study also represents an attempt to answer the key question "How does zooplankton grazing pressure of short-time variability regulate the corresponding phytoplankton standing crop in a highly dynamic marine area off Alexandria?".

MATERIALS AND METHODS

The measurements were conducted at a fixed station (3 m depth) located at about 100 m west of Kayet Bey fort, in the neritic open sea waters off Alexandria. The sampling area is subjected to different land-based sources mainly the Kayet Bey sewer and Umum drain.

Short-time sampling was collected from 1 September 2000 to 15 August 2001 (41 samples). The measured parameters included the surface and over bottom temperature (by a thermometer accurate to $\pm 0.1^{\circ}\text{C}$) and salinity (salinity refractometer). The nutrient salts essential for phytoplankton growth were measured in surface water, namely the dissolved inorganic nitrate, silicate and phosphate according to the method of Strickland and Parsons (1972).

Two liters of seawater were collected from the surface for determination of phytoplankton standing crop, community structure and species composition. The fresh samples were first examined by an inverted microscope to identify flagellate species. These include unarmoured dinophycean, raphidophycean and microflagellates species that could be distorted by the addition of formalin fixative. The sample was then fixed and counted (Utermohl, 1958).

Zooplankton samples were collected by vertical hauls from near bottom to surface using a plankton net (55 μm mesh, 50 cm diameter). The buffered formalin (4% final concentration) was added for preservation. The zooplankton abundance, population structure and species composition were determined and calculated as organisms m^{-3} .

The following references have been consulted for the identification of the phytoplankton and zooplankton species: Tregouboff and Rose (1957), Edmondson (1959), Hendey (1964), Park and Dixon (1976), Dodge (1982), and Sournia (1986).

The statistical approach includes the matrix correlation and the multiple linear regression.

RESULTS

Phyto-zooplankton structure

The phyto-zooplankton abundance and community structure are shown in Figure 1.

Generally, the peaks of the standing crop were mainly attributed to an increase in diatom abundance, which contributed an annual average of 1.46×10^6 cell l^{-1} (79.4 %), followed in abundance by dinoflagellates (0.24×10^6 cell l^{-1} , 9.19 %), microflagellates (0.21×10^6 cell l^{-1} , 8.18 %), and euglenophytes (0.06×10^6 cell l^{-1} , 2.29 %).

Zooplankton abundance (annual average of 3.69×10^6 org. m^{-3}), included mainly copepods (average 1.54×10^6 org. m^{-3} , 41.76 %), protozoans (0.72×10^6 org. m^{-3} , 19.5 %), cirriped larvae (0.31×10^6 org. m^{-3} , 8.25 %), and annelida (7.8 %), while ostracods (2.02 %) and rotifers (1.46 %) were of minor contribution.

Seasonal variations

Autumn

The phytoplankton standing crop was rich (0.34×10^6 - 7.4×10^6 cell l^{-1}) and diatoms prevailed (72.3 %). The Dinoflagellates *Prorocentrum triestinum* and *Scrippsiella trochoidea* dominated in early September. Diatoms contributed 4 major peaks. *Thalassiosira subtilis* represented the main component on 7 September (3×10^6 cell l^{-1}), with *Euglena gracile* (26 %) at 27.2 °C, 35.5 ‰, nitrate and phosphate around 2.7 μ M and very reduced silicate (0.84 μ M). *Rhizosolenia delicatula* (1.5×10^6 cell l^{-1} , 38.44 % on 14 September), *R. fragilissima*, *Nitzschia longissima*, *Skeletonema costatum* and *Chaetoceros affinis* were of minor contribution. On 15 October, *Thalassiosira pseudonana* became leading (0.5×10^6 cell l^{-1} , 34.75 %), followed by the dinoflagellates, *Protoperdinium depressum* (20.55 %) and *Gymnodinium mikimotoi* (9 %) and *Pyramimonas* spp., (8.56 %). *Micromonas* spp. attained its peak on 26 October (7×10^6 cell l^{-1} , 93.4 %) at a reduced nitrate (1.2 μ M), and exhausted silicate (0.75 μ M). *Chaetoceros laceriosus* was dominating in early November (1.2×10^6 cell l^{-1} , 70 %) at 22 °C, 21.5 ‰, and 2.25, 1.2 and 1.45 μ M for nitrate, silicate and phosphate. Other minor species were *Asterionella glacialis* (0.23×10^6 cell l^{-1} on 14 November), and *T. pseudonana* (0.16×10^6 - 0.22×10^6 cell l^{-1} on 22-28 November). *Chaetoceros affinis*,

Rhizosolenia hebetata and *Pseudonitzschia australis* were of less importance.

Zooplankton abundance in autumn was relatively rich (average 5.12×10^6 org. m^{-3}), the population never fell down below 2×10^6 org. m^{-3} , with two major peaks in the middle and late September (14×10^6 and 11.74×10^6 org. m^{-3} , respectively), the first one was the highest throughout the year. Other small peaks appeared in early-late October (around 8×10^6 org. m^{-3} , for each). Copepoda represented the main constituent of the population (average 2.26×10^6 org. m^{-3} , 39.78 %), with maximum number on 14 and 28 September (8.5×10^6 , 60.94 % and 5.8×10^6 org. m^{-3} , 49.41 %). Protozoa shared the dominance of the former (19.12 %), while Annelida contributed 12.32 % with the latter bloom. Adult copepods with the major peaks contributed 42-80.3 % of the total Copepoda, and were mainly represented by *Acartia clausi*, *A. grani*, *Centropages*, *Euterpina*, *Paracalanus* spp., and *Oithona nana*. Copepod nauplii ranked the second level, with the highest of 3.1×10^6 org. m^{-3} , 35.86 % on 14 September and copepodite stages on 26 October (0.77×10^6 org. m^{-3} , 37.76 %).

Concerning the phyto-zooplankton relationship, several concepts could arise: the peak of the zooplankton stock on 14 September was met by a slight phytoplankton decrease compared with that of the previous level on 7 September. Despite the well diversified phytoplankton community, mostly of diatoms, with the centric *R. delicatula* being the dominant form (38.44 %); the reverse relation was obvious, particularly between late September - early October, as well as in late November, when the grazing pressure inflicts losses on the standing crop. A parallel relation was found between the increased phyto-zooplankton density on 26 October, when *Micromonas* spp. predominated.

Winter

Despite the low phytoplankton (average of 0.37×10^6 cell l^{-1}), there was remarkable increased numbers at times, attributed to diatom prevalence (90.3 %). The major peak on 5 December (1.35×10^6 cell l^{-1}) caused by *T. pseudonana* (95.56 %), which consumed most of the nutrients (0.45, 0.6 and $0.85 \mu M$ for NO_3 , SiO_4 , and PO_4); *A. glacialis* was responsible for the minor peak in late December and early February (0.14×10^6 and 0.18×10^6 cell l^{-1}), and *S. costatum* in late February (0.63×10^6 cell l^{-1} , 69.32 %).

The zooplankton stock was reduced compared with autumn (2.71×10^6 org. m^{-3}), probably affected by the lower winter

temperature and the corresponding reduced standing crop. Generally, the density fluctuated between 1.01×10^6 and 2.45×10^6 org. m^{-3} . However, a distinct peak appeared in mid-January (12.78×10^6 org. m^{-3}), due to the combination of protozoans (5.9×10^6 org. m^{-3} , 46.42 %) and copepod spp. (5.51×10^6 org. m^{-3} , 43.08 %). Tintinnids (5.53×10^6 org. m^{-3}) contributed the main bulk of protozoan spp. Meanwhile, the Copepoda structure (Figure 5) showed almost similar frequency percentage of its 3 groups, with a slight increase for Copepod nauplii (2.03×10^6 org. m^{-3} , 36.86 % of the total Copepoda).

The co-occurrence of phyto-zooplankton population reflects a clear inverse relation in February, when the water column was characterized by homothermal, homohaline condition, and diatoms were the majors (88.66-100 %). However, the grazing pressure exhibited some differential features: the remarkable standing crop increase on 27 December (0.32×10^6 cell l^{-1}) was accompanied with slightly higher zooplankton stock (1.33×10^6 org. m^{-3}), when *A. glacialis* and *C. affinis* dominated the community; the same situation was observed on 26 January (*Biddulphia aurita*, microflagellates, *R. delicatula*, and *S. costatum*); an inverse relation between the increased standing crop and the sharply reduced zooplankton stock took place with the start and the end of February where *Chaetoceros* spp., predominated.

Spring

Spring represented the highly productive season (average 4.88×10^6 cell l^{-1}), with several diatoms euglenas and microflagellate peaks. Except for the massive occurrence of microflagellates and euglenophytes in May, diatoms comprised the main bulk of the community (95.5-99.9 %). *C. affinis* was leading in March followed in abundance by the overwhelming dominance of *S. costatum* in April (9×10^6 cell l^{-1} , 93.94 % on 3 April), associated with *A. glacialis* (1.15×10^6 cell l^{-1} , 57.86 % on 11 April). *Pyramimonas* spp., contributed a distinct bloom on 7 May ($>20 \times 10^6$ cell l^{-1} , 97.12 %) at a thermo-haline stratified condition, and severely consumed nutrients (0.5, 0.8 and 0.8 μM for NO_3 , SiO_4 , and PO_4). By mid-May, the euglenophyte, *Euglena spirogyra* became dominant (2.3×10^6 cell l^{-1} , 39.5 %), while *P. minimum* contributed 1.8×10^6 cell l^{-1} , 28.91 %.

Despite the lower average of the zooplankton population (2.47×10^6 org. m^{-3}) in spring, compared with winter (affected by its major peak on 14 January), the density was generally higher, but without any distinct peak. The period between early March-early April was the most productive (3.1×10^6 - 3.9×10^6 org. m^{-3}), which accompanied the

noticeable surface temperature increase and the initiation of the thermo-haline stratification of the water column; as well as during the other period in the latter month (2.7×10^6 - 3.6×10^6 org. m^{-3}) with reduced salinity. Copepoda species were still the dominant forms (average 1.6×10^6 org. m^{-3} , 58.74 %), followed in abundance by Annelida (0.22×10^6 org. m^{-3} , 7.75 %), and Protozoa (0.18×10^6 org. m^{-3} , 7.5 %). The adult Copepoda dominated at times, particularly in the first two weeks of April (57.7 - 68 %), as well as in mid-late May with almost similar contribution. *Acartia* species represented by 0.62×10^6 org. m^{-3} on 11 April.

The zooplankton pressure showed different patterns: the phytoplankton peak on 3 April (*S. costatum* predominated) accompanied with almost unchangeable zooplankton stock; a sharp drop in zooplankton population (1.9×10^6 org. m^{-3}) was found with the massive occurrence of *Micromonas* spp., in the second week of May; a similar result was detected on 15 May (1.7×10^6 org. m^{-3}), when the phytoplankton community comprised mainly *Euglena spirogyra*, *P. minimum*, *P. triestinum* (0.4×10^6 cell l^{-1}), and *P. australis* (0.7×10^6 cell l^{-1}).

Summer

Summer attained an average of 3.15×10^6 cell l^{-1} , mostly of diatoms (84.9 %) and dinoflagellates (8.5 %). The major phytoplankton peak (10.5×10^6 cell l^{-1}) occurred on 8 June (*S. costatum* and *Micromonas* species, 62.3 % and 28.25 %, respectively), at 1.4, 1.6 and 1.7 μM for NO_3 , SiO_4 , and PO_4 . The first species dominated in June, with *P. minimum* (0.4×10^6 cell l^{-1} , 31.64 % on 16 June), and *R. delicatula*. Recurrent massive occurrence occupied the period between 24 July and 15 August. *S. costatum* and *T. pseudonana* dominated in early August followed in abundance by *Cylindrotheca closterium*. The latter became leading on 15 and 18 August (3.7×10^6 and 2.5×10^6 cell l^{-1} , respectively). Accompanied nutrients with the summer peaks were relatively low (0.7-1.5 μM NO_3 , 0.5-2.2 μM SiO_4 and 0.9-3.2 μM PO_4).

As for the zooplankton abundance, the period from early June to late July did not show considerable variation in the zooplankton stock compared with spring. However, the pronounced increase that occurred in August raised the summer average to 3.95×10^6 org. m^{-3} . Protozoa species (1.19×10^6 org. m^{-3} , 30.15 %) contributed the main component, followed by Copepoda (0.89×10^6 org. m^{-3} , 22.63 %) and Annelida species (9.97 %). The major peak on 2 August (11.8×10^6

org. m⁻³) characterized by the proliferation of Protozoa (7.45x10⁶ org. m⁻³, 63.17 %) and Copepoda spp., (1.2x10⁶ org. m⁻³, 10.2 %). The density during the rest of August fluctuated between 4.8x10⁶ and 5.4x10⁶ org.m⁻³, with the dominance of Copepoda (26.3-30.7 %), and Protozoa (12.4-17.8 %). The adult Copepoda contributed 39.47 - 81.74 % of the total Copepoda, *Oithona* species was dominated, followed in abundance by *Paracalanus* spp.

Regarding the phyto-zooplankton relation, a general suggestion of the massive grazing pressure on the standing crop was proved. However, the intensive phytoplankton increase on 8 June was not accompanied by similar zooplankton behavior, despite *S. costatum* formed 62.3 % of the total community, and shared in active role by *Micromonas* spp. (28.25 %). An increasing positive relation was detected on 2 August, when *S. costatum*, *T. pseudonana*, and *Cylindrotheca closterium* dominated the community.

The correlation matrix (Table 1) shows the surface temperature to be positively, significantly correlated with diatoms. Salinity exhibits significant contribution with the phytoplankton community structure, except microflagellates. Nitrate positively correlated with diatoms, but negatively, significantly related to microflagellates. Silicate was positively correlated with the variability of diatoms, significantly inversely correlated with euglenophytes. Phosphate showed positive relation with the community components, except microflagellates.

Concerning the zooplankton variability formula :

$$\begin{aligned} \text{The zooplankton abundance (org.} \times 10^6 \text{ m}^{-3}\text{)} = & - 23169 + \\ & 369.51 * \text{Temperature} \\ & + 431.44 * \text{Salinity} - 1682.5 * \text{NO}_3 + 927.76 * \text{SiO}_4 + 620.73 * \text{PO}_4 \\ & R^2 = 0.45, p < 0.05 \end{aligned}$$

The model predicts positive influence of the variables measured on the zooplankton levels, except for nitrate; salinity for its high correlation coefficient was the major contributory, significant at $p < 0.05$; nitrate influence was the highest, followed by silicate and phosphate; and these variables together explain 45 % of the zooplankton variability. The predicted relation of temperature and salinity are shown in Figure 2.

The correlation matrix (Table 1) shows that the temperature was significantly correlated with the variability of annelids and copepodite stages, and negatively with the latter. Salinity exhibits significant correlation with copepods. Nitrate shows significant, negative correlation with protozoans rotifers, and adult copepods and positively with nauplius larvae. Silicate positively significantly

correlated with copepodite stages and nauplii, while phosphate with protozoans and rotifers.

DISCUSSION

The phytoplankton variability exhibited some distinct features as the dominance of diatoms in winter; *Pyramimonas* species showed their peaks in transient periods in October and May at temperature around 20°C and stable water column. The rapid change in the phytoplankton community structure (*Pyramimonas* species bloom was replaced immediately by *Euglena spirogyra* in May); and the massive diatom blooms in summer.

The present major peaks caused by *Micromonas* and *Pyramimonas* species reflect symptoms of eutrophication, which led to an increase of non-diatom species (Cadee, 1992).

The zooplankton variability exhibited patterns almost similar to that of the standing crop: large seasonal variations, with minimum in February affected by the low standing crop contribution and the lower temperature, and a maximum in September; a pronounced increase in early spring under the previously mentioned environmental condition which enhanced also the occurrence of the standing crop; several major peaks, two in autumn, one in mid-winter and one in late summer; copepod spp., were responsible for the first peak (61% of the total), and it was shared relatively by Protozoa (19.12 %), while Copepoda (49.41%) and annelida (12.32 %) dominated in the second autumn peak on 28 September, Copepoda and Protozoa in mid-winter bloom (43.1 and 46.42 % on 14 January), and the latter group for the last one on 2 August; adult Copepoda and/or copepodite stages and nauplii larvae dominated; and *Oithona nana*, *Acartia* and *Euterpina* spp. were majors. The dominance of Protozoa in summer agrees with the results of Cattoni and Corni (1992).

Comparing the present data with that carried out in the Eastern Harbour during 1986-87 (Aboul Ezz and Hussein, 1990), Protozoa was previously reported in the harbour to contribute the major fraction of the zooplankton with 42.1 % of the total, rotifers (37.1 %), and Copepods (15.9 %). The authors added that the abundance peak of Protozoa was recorded in spring (average 0.35×10^6 org. m^{-3}), rotifers in August (74.9 %), and with other two minor peaks in February and in April, mainly of tintinnids (30 and 78 %). On the other hand, Copepoda was very low in winter, and attained the

highest level (0.13×10^6 org. m^{-3}) in September 1986, and copepodite nauplii contributed 60% of the total copepoda.

The remarkable plankton variations observed, beside those of salinity and ambient nutrient concentrations could be explained as direct impact of the anthropogenic activity and the arrival of different water masses by transport processes, with different properties. Eutrophication regulates the extent of primary production and plankton abundance (Malej *et al.*, 1998). The large seasonal variations observed in many estuarine and coastal systems have been related to fresh water run-off (northern Adriatic Sea: Gilmartin *et al.*, 1990, San Francisco Bay: Harding, 1994; Kiel Bight: Maske, 1994; Mozetic *et al.*, 1998).

Phytoplankton variability apparently was under the control of temperature and salinity, and nitrate and grazing at time. The statistical analyses showed salinity a significant environmental factor controlling the variability of the phytoplankton groups. According to Watras *et al.* (1982) temperature and salinity appeared to be the factors that mostly influenced algal bloom development.

Zooplankton abundance was also affected by multi-factorial control with temperature and salinity, in particular the latter variable to be the major. The relation between enriched nutrients (anthropogenic eutrophication) and the zooplankton dynamics observed, could be ascribed simply to the essential role played by nutrients to limit the phytoplankton growth, which in turn influences the co-occurrence of the zooplankton stock and population. The low temperature in early February despite the increased standing crop indicates the far known conclusion that low temperature reduces grazing (Martin, 1965). Meanwhile, the increased phytoplankton and zooplankton densities in early March with a noticeable rise in temperature supports the conclusion of Huntley and Lopez (1992), and Coversi and Hamed (1998) that zooplankton growth rates and those of their prey (phytoplankton) are positively affected by an increase in temperature in spring. Copepoda species responsible for the increased zooplankton in spring were mainly represented by *Acartia* spp. (mostly *A. clausi*). This species was previously reported in the harbour as a major contributory (Aboul Ezz and Hussein, 1990). According to Fernandez (1978), *A. clausi* compensated for temperature variation to a greeter degree than other copepod species. Wlodarczyk *et al.* (1992) documented the increased effect of increased temperature on the grazing pressure of *Acartia* species on *Thalassiosira* spp. Salinity was also known to affect the zooplankton

seasonal variation and composition (Ojaveer *et al.*, 1998). The major peaks, except of mid-January, maintained relatively low surface salinity (34-37.5 psu).

The present data shows that zooplankton grazing has been postulated to play at times an effective role in regulating the phytoplankton cycle, and inflicts losses on the numerical standing crop. Yet, a key question is whether the grazing pressure can be expected to be sufficiently high to affect the phytoplankton standing crop to the extent observed. The statistical model of :

Zooplankton abundance = 3683.07 + 1.405*phytoplankton concentration, $R^2 = 0.000003$, $p > 0.05$.

The model predicts a positive, but a very weak correlation (Figure 3). The distribution of diatoms (the major phytoplankton component) and copepods (the major herbivorous) is shown in Figure 3. The statistical model predicts insignificant positive relation between copepods and diatoms:

Copepoda = 672.9 + 11.017*Diatoms $R^2 = 0.0317$, $p > 0.05$

The correlation matrix (Table 1) indicates insignificant positive correlation of diatoms and copepods, negative with ostracods and adult copepods; dinoflagellates (Figure 3), while euglenophytes also exhibited insignificant, reverse relation with most of the zooplankton structural components.

Considering the large seasonal zooplankton variation under multi-factorial control of the environmental variables measured, the expected direct impacts of the eutrophication and the water exchange with newly induced physico-chemical and biological properties, different patterns of the grazing pressure could be distinguished:

1- Top-bottom (inverse) relationship: It was obvious at intermittent periods during the different seasons with the overwhelming prevalence of diatoms (centric and pennate forms). Thus; in late February at the homothermal and homohaline conditions, with predominance of *S. costatum*; in late September-early October associated with the well established stratified water column, with *S. costatum*, *T. subtilis*, *T. pseudonana*, and *Thalassionema nitzschioides*; and in summer with *S. costatum* and *T. pseudonana*. All these species had 20-50 μm length (Labib and Kamel, 2000d). Such inverse relationship between the relative quantities of phytoplankton and zooplankton had been noted previously in the harbour, based on monthly sampling during 1986-1987, throughout the vertically stratified water periods (May-October, Aboul Ezz and

Zaghloul, 1990), as well as elsewhere (Li and Smayda, 1998). Grazing by herbivorous zooplankton is often a major loss factor for phytoplankton, and when grazers are abundant, they can suppress bloom development (Uye 1986). Accordingly, when algae are adapted to escape grazing in some way, this is a beneficial strategy to increase their net growth rate as long as nutrients are available.

2- Reduced grazing pressure connected with specific diatom species: several examples could be followed at intermittent periods; on 14 September, when diatoms dominated at a well developed thermo-haline stratification, mainly represented by *R. delicatula*; on 4 November, with *C. laceriosus* (70 % of the total community); on 27 December (but with the interference of other environmental factors, the reduced temperature), with *A. glacialis* and *C. affinis*; on 26 January when, *R. delicatula* regained its dominance, beside others; and in the start and the end of February, *C. affinis*, in combination with *C. decipiens* and *C. curvesitus* contributed the main bulk of the community. The success of *R. delicatula* to grow well under the stabilized water condition, which favor the flagellate blooms agrees with other observations the in harbour (Labib, 1994 a,b), as well as for other *Rhizosolenia* species (Parrey *et al.*, 1989). *Rhizosolenia* species were suggested to be unpalatable to zooplankton grazers (Deniseger *et al.*, 1986). It has often been suggested that spiny or needle-like phytoplankton cells are less favored by some zooplankton than simple chain forms with cylindrical cells (Conover and Mayzaud, 1984; Parrey *et al.*, 1989). Meanwhile, the grazing pressure may have been decreased further due to a relatively lower predation pressure on colony-forming *Chaetoceros* than on diatoms, similar to the conclusion of Estep *et al.* (1990) and Weisse *et al.* (1994), that *Chaetoceros* species were recorded not so actively grazed. Its predominance in the harbour during March 1987, was associated with lower zooplankton abundance (Aboul Ezz and Zaghloul, 1990). It is also possible that consumers avoid the uptake of *A. glacialis* due to its shape, aggregation, and large size (>100 μm , Labib and Kamel, 2000d). Berggreen *et al.* (1988) verified that copepods prefer phyto-cells smaller than 100 μm . It has been demonstrated that several phytoplankton species are grazed to a lesser extent than others due to their size and/or shape (Riegman *et al.*, 1992; Graneli *et al.*, 1993b), or their ability to clump in aggregates (Hansen *et al.*, 1992).

3- Reduced grazing pressure connected with specific phytoplankton community structure: several cases were reported;

such as the mixed community on 7 September of the centric diatoms, *T. subtilis*, *R. fragilissima*, *C. affinis*, the pennate *P. australis*, and the euglenophyceae, *Euglena gracile*; on 15 October of *T. pseudonana* (34.75 %), the dinoflagellates *Protoperidinium depressum* (20.55 %), *Gymnodinium mikimotoi* (9 %) and the microflagellate *Pyramimonas* species (8.56 %); and on 15 May of *Euglena spirogyra*, the dinoflagellates, *P. minimum* and *P. triestinum*, and the centric diatom, *S. costatum*. The observed increased frequency of non-diatom cells, and the sharp decline of the centric diatoms (except *Rhizosolenia* and *Chaetoceros* species) indicate the possible avoidance of zooplankton consumers to take up the non-diatom cells as long as the smaller producers (*T. subtilis*, *T. pseudonana*, *S. costatum*) were present, offering some advantage to non-diatom species to dominate. Another example was seen on 8 June, when the phytoplankton peak of *S. costatum* and *Micromonas* spp., accompanied with relatively low zooplankton abundance. The concentration of *S. costatum* was severely dropped after one week. Therefore, zooplankton grazing pressure could help the change in dominance, beside factors as the competition of diatoms with flagellate species, when zooplankton population was low (Lancelot, 1995). *S. costatum* was far known a suitable prey, and ratios from 0.5 to 65 % of *Acartia clausi* wet body weight fed on *S. costatum* with measured (Petipa, 1966). The *Acartia* spp. (*A. bifilosa*, *A. clausi*, *A. grani*, and *A. latistosa*) reached their maximum abundance on 11 April at 14.7 °C. According to Deason (1980) *A. clausi* compensated maximum filtration at 14-15 °C, and it showed critical thermal maxima of 22-28 °C (Gonzalez, 1974).

4- Inability of grazing to control phytoplankton blooms: despite the increased abundance of zooplankton, these consumers proved not to be able to control the development of the microflagellates (*Micromonas* spp.) accumulated on 26 October. Other accompanied minor species *C. affinis*, *Rhizosolenia hebetata*, and *P. australis*, seem less favored by some zooplankton. Meanwhile, the red tide bloom of *Pyramimonas* spp., the highest over the year round on 7 May seems relatively immune to grazing. Reasons for such different grazing patterns could include the shared occurrence of other diatom species with the first bloom and the mono-specific nature of the second heavy bloom and inadequate nutritional food of other algae. The copepod *Acartia hudsonica* and larvae of the polychaete *Polydora* spp. do consume the toxic dinoflagellate *Gonyaulax tamarensis* in presence of other phytoplankton species (Anderson *et*

al., 1983). There was an active avoidance of copepods for the dinoflagellates *P. triestinum* and *Scrippsiella trochoidea* with their maximum densities in the harbour (Labib & Hussein 1994, labib 2000c), in accordance with Huntely (1982), and experimentally for the dinoflagellate *Alexandrium ostenfeldii* (Hansen *et al.*, 1992). Reduced zooplankton grazing pressure has been implicated as primary bloom trigger (Sellner and Fonda Umani, 1998).

5- Time lag relationship: the variation in time between phytoplankton and zooplankton increase led to a remarkable phytoplankton proliferation between 7-14 September and 24 July-2 August. The massive zooplankton occurrence followed such pronounced phytoplankton increase within a week.

6- Positive increasing relationship: the greater phytoplankton standing crop in early April, when *S. costatum* contributed its distinct peak, as well as in early August when the predominance was shared by the same species, beside *T. pseudonana*, and *C. closterium*, reflected an increasing zooplankton abundance. Although a large zooplankton population was present, the production of these species, known as fast-growing (Mozetic *et al.*, 1998) was high enough to maintain the crop. Cataletto *et al.* (1995) and Mozetic and Lipej (1998) proved such positive relationship.

ACKNOWLEDGEMENT

The author deeply appreciates the great help offered by Mrs. Nabila Kotb, Institute of Oceanography and Fisheries, Alexandria in the analysis of the zooplankton samples.

REFERENCES

- Aboul Ezz, S. and Hussein, M. (1990). Effect of domestic sewage discharge on the distribution of zooplankton organisms in the Eastern Harbour of Alexandria (Egypt). The bulletin of the High Institute of Public Health, 20(4): 861-874.
- Aboul Ezz, S. and Zaghloul, F. A. (1990). Phytoplankton-zooplankton relationship in the surface water of the Eastern Harbour (Alexandria). Bull. Nat. Inst. Oceanogr. & Fish., ARE, 16 (1), 19-26.

- Anderson, D. M. ; Chisholm, S. W. and Watras, C. J. (1983). The importance of life cycle events in the population dynamics of *Gonyaulax tamarensis*. *Marine Biology*, 76: 179-190.
- Berggreen, U. ; Hansen, B. and Kiorboe, T. (1988). Food size spectra, ingestion and growth of the copepod *Acartia tonsa* during development implication for determination of copepod production. *Marine Biology*, 99: 341-352.
- Cadee, G. C. (1992). Trends in Marsdiep phytoplankton. Publication Series Netherlands Institute for Sea Research, 20: 143-149.
- Carpenter, S. R. and Kitchell, J. F. (1993). The trophic cascade in lakes. Cambridge Univ. Press. 390 pp.
- Catalleto, B. ; Feoli, B. ; Fonda Umani, S. and Sun, C. Y. (1995). Eleven years of time-series analysis on the net-zooplankton community in the Gulf of Trieste. *ICES Journal of Marine Science*, 52: 669-678.
- Cattani, O. and Corni, M. G. (1992). The role of zooplankton in eutrophication, with special reference to the Northern Adriatic Sea. In: *Marine Coastal Eutrophication*, Vollenweider, R. A., Marchetti, R., and Viviani, R. (eds.). Elsevier, 137-158.
- Colijn, F. (1998). The temporal variability of plankton and their physico-chemical environment. *ICES Journal of Marine Science*, 55: 557-561.
- Conover, R. J. and Mayzaud, P. (1984). Utilization of phytoplankton by zooplankton during the spring bloom in Nova Scotia inlet. *Can. J. Fish. Aquat. Sciences*, 41: 2323-244.
- Coversi, A. and Hamed, S. (1998). Common signals between physical and atmospheric variables and zooplankton biomass in the subarctic Pacific. *ICES Journal of Marine Science*, 55: 739-747.

- Deason, E. E. (1980). Grazing of *Acartia hudsonica* (*A. clausi*) on *Skeletonema costatum* in Narragansett Bay (USA): Influence of Food Concentration and Temperature. *Marine Biology*, 60: 101-113.
- Deniseger, J. ; Austin, A. ; Roch, M. and Clark, M. J. R. (1986). A persistent bloom of the diatom *Rhizosolenia eriensis* (Smith) and other changes associated with decreases in heavy metal contamination in an oligotrophic lake, Vancouver Island. *Enviro. Expl. Bot.*, 26: 217-226.
- Dodge, J. D. (1982). Marine dinoflagellates of the British Isles. Her Majesty's Stationery Office, London, 303 pp.
- Edmondson, W. T. (1959). Fresh water biology. 2nd ed. John Wiley and Sons. Inc. New York and London. XX, 1248 pp.
- Estep, K. W. ; Nejstgaard, J. Ch. ; Skjoldal, H. R. and Rey, F. (1990). Predation by copepods upon natural population of *phaeocystis pouchetti* as a function of the physiological state of the prey. *Marine Ecology Progress Series*, 67: 235-249.
- Fernandez, F. (1978). Metabolism y alimentacion en copepods planctonicos del Mediterraneo: Respuesta a la temperatura. *Inv. Pesq.*, 42: 97-139.
- Gilmartin, M. ; Degobbis, D. ; Revelante, N. and Smolaka, N. (1990). The mechanism controlling plant nutrient concentrations in the north Adriatic Sea. *Internationale Revue der gesamten, Hydrobiologia*, 75: 425-445.
- Gonzalez, G. (1974). Critical thermal and upper lethal temperature for the Calanoid copepods *Acartia tonsa* and *A. clausi*. *Marine Biology*, 27: 219-223.
- Graneli, E. ; Olsson, P. ; Carlsson, P. ; Graneli, W. and Nylander, C. (1993 b). Weak top-down control of dinoflagellate growth in the coastal Skagerrak. *Journal Plankton Research*, 15: 213-237.

- Hansen, P. J. ; Cembella, A. D. and Moestrup, (1992). The marine dinoflagellate *Alexandrium Osterfeldii*: Paralytic shellfish toxin concentration, composition and toxicity to a Tintinnid Ciliate. *Journal Phycology*, 28: 597-603.
- Harding, L. W. Jr. (1994). Long term trends in the distribution of phytoplankton in Chesapeake Bay: roles of light, nutrients and streamflow. *Marine Ecology Progress Series*, 104: 267-291.
- Hendey, N. I. (1964). An introductory account of the smaller algae of British Coastal Waters, Part 5, Bacillariophyceae. *Minist. Agric. Food Invest. Ser.*, London, Series. 317 pp., 45 pl.
- Huntley, M. E. (1982). Yellow Water in La Jolla Bay California, July 1980. II Suppression of zooplankton grazing. *Journal experimental Marine biology and ecology*, 63: 81-91.
- Huntely, M. E. and Lopez, M. D. G. (1992). Temperature dependent production of marine copepods: a global synthesis. *American Naturalist*, 140: 201-242.
- Justic, D. ; Rabalais, N. N. ; Turner, R. E. and Dortch, Q. (1995). Changes in nutrient structure of river-dominated coastal waters stoichiometric nutrient balance and its consequences. *Estuarine, Coastal and Shelf Science*, 40: 339-356.
- Labib, W. (1994a). Ecological study of spring-early summer phytoplankton blooms in a semi-enclosed estuary. *Chemistry and Ecology*, 9: 75-85.
- Labib, W. (1994b). Massive algal pollution in highly eutrophic marine basin, Alexandria, Egypt. The 4th Conf. of the Environ. Prot. is a must, 10-12 May 1994: 181-194.
- Labib, W. (2000c). Dinoflagellate Brown Tides in Alexandria, Egypt waters during 1997-1998. *Pakistan Journal of Marine Sciences*, 9 (1): 33-49.

- Labib, W. and Hussein, M. (1994). Water discoloration in Alexandria, Egypt, April 1993. 2- Factors controlling the dissipation of the dinoflagellate *Prorocentrum triestinum* Schgiller Red Tide bloom. Alexandria Science Exchange, 15 (4): 481-494.
- Labib, W. and Kamel, S. (2000d). Relative importance of the size-fractionated phytoplankton population in temperate waters, Alexandria (Egypt). Egypt. J. Aquat. Biol. & Fish., 4 (1): 47-66.
- Lancelot, C. (1995). The mucilage phenomenon in the continental coastal water of the North Sea. Science of the total environment, 195: 83-102.
- Li, Y. and Smayda, T. J. (1998). Temporal variability of chlorophyll *a* in Narragansett Bay. ICES Journal of Marine Science, 55: 661-667.
- Lluch-Belda, D. ; Crawford, R. J. M. ; Kawasaki, T. ; MacCall, A. D. ; Parrish, R. H. ; Schwartzlose, R. A. and Smith, P. E. (1989). Worldwide fluctuations of sardine and anchovy stock: the regime problem. South African Journal of Marine Science, 8: 195-205.
- Malej, A. ; Mozedic, P. ; Turk, V. ; Terzic, S. ; Ahdel, M. and Cauwet, G. (1998). Effects of nutrient addition on phytoplankton/bacterioplankton interactions and dissolved organic matter variability. Part I. Productivity aspect. In: Ecosystem Research Report, the Adriatic Sea, EU/Environmental Series, Brussels (in press).
- Martin, J. H. (1965). Phytoplankton-zooplankton relationship in Narragansett Bay. *Limnology and Oceanography*, 10: 185-191.
- Maske, H. (1994). Long-term trends in seston and chlorophyll *a* in Kiel Bight, Western Baltic. Continental Shelf Research, 14 (7/8): 791-801.

- Mozetic, P. and Lipej, L. (1998). Phytoplankton-zooplankton trophic interactions along the salinity gradients (Gulf of Trieste). Rapport de la Commission Internationale pour L'Exploration Scientifique de la Mer Mediterranee, 35: 468-469.
- Mozetic, P. ; Fonda Umani, S. ; Cataletto, B. and Malej, A. (1998). Seasonal and inter-annual plankton variability in the Gulf of Trieste (Northern Adriatic). Journal of Marine Science, 55: 711-722.
- Ojaveer, E. ; Lumberg, A. and Ojaveer, H. (1998). Highlights of zooplankton dynamics in Estonia waters. ICES Journal of Marine Science, 55: 748-755.
- Officer, C. B. ; Smayda, T. and Mann, R. (1982). Benthic filter feeding: a natural eutrophication control. Marine Ecology Progress Series, 9: 203-210.
- Park, M. and Dixon, P. S. (1976). Check-list of British marine algae. Third revision, J. Mar. Biol. Ass. U. K., 56: 527-594.
- Parry, G. D. ; Langdon, J. S. and Huisman, J. M. (1989). Toxic effect of a bloom of the diatom *Rhizosolenia chunii* on shellfish in Port Phillip Bay, Southern Australia. Marine Biology, 102: 25-41.
- Pennock, J. R. and Sharp, J. H. (1994). Temporal alternation between light-and nutrient limitation of phytoplankton production in a coastal plain estuary. Marine Ecology Progress Series, 111: 275-288.
- Petita, T. S. (1966). Relationship between growth, energy metabolism, and ration in *Acartia clausi*. In: Physiology of Marine Animals, 82-91. Akad. Nauk. SSSR, Oceanographically Commission.

- Riegman, R. ; Noordelos, A. A. and Cadee, G. C. (1992). *Phaeocystis* blooms and eutrophication of the continental zones of the North Sea. *Marine Biology*, 112: 479-484.
- Sellner, K. G. and Fonda Umani, S. (1998). Dinoflagellate blooms and mucilage production. In: Land-Use, Water Quality and Fisheries: a Comparative Ecosystem Analysis of the Northern Adriatic Sea and Chesapeake Bay. American Geophysical Union (in press).
- Smayda, T. J. (1990). Novel and nuisance phytoplankton blooms in the sea: evidences for global epidemic, *In: Toxic Marine Phytoplankton*, pp. 29-40, E. Graneli, B. Sundstrom, L. Edler, and D. M. Anderson (eds.), Elsevier, Amsterdam. 554 pp.
- Sournia, A. (1986). Atlas du phytoplancton marine. Vol., I. Cyanophycees, Dictyochophycees, Dinophycees et Raphidophycees. Ed. du CNRS, Paris, 219 pp.
- Strickland, J. D. and Parsons, T. R. (1972). A practical handbook of sea water analysis, 2nd Edition Bulletin Fisheries Research Board Canada 167 pp.
- Tregouboff, G. and Rose, M. (1957). Manuel de planctonologie mediterraneene. Paris, Ed., du., C.N.R.S., 2nd Vol., 587 pp.
- Utermohl, H. (1958). Zur Vervollkommnung der Quantitativen Phytoplankton Methodik. *Mitt. Int. Ver. Theor. Angew. Limnology*, 9: 1-38.
- Uye, S. (1986). Impact of copepod grazing on the red tide flagellate *Chatonella antiqua*. *Marine Biology*, 92: 35-43.
- Verheyc, H. M. ; Richardson, A. ; Huchings, L. ; Marska, G. and Gianakouras, D. (1998). Long-term trends in the abundance and community structure of coastal zooplankton in the southern Benguela system, 1951-present. *In: Benguela dynamics. Impacts of variability on shelf-sea environments and their living resources*. Pilar, S. C. ; Moloney, C. L. ; Payne, A. I. L. and Shillington, F. A. (eds.) *South African Journal of Marine Science*, 19 (in press).

- Watras, C. J. ; Chisolm, S. W. and Anderson, D. M. (1982). Regulation of growth in an estuarine clone of *Gonyaulax tamarensis*: salinity-dependent temperature response. *Journal Experimental Marine Biology Ecology*, 62:25-37.
- Weisse, T. ; Tande, K. ; Verity, P. ; Hansen, F. and Gieskes, W. (1994). The significance of *Phaeocystis* blooms. *Journal of Marine Systems*, 5: 67-79.
- Wlodarczyk, E. ; Durbin, A. G. and Durbin, E. G. (1992). Effect of temperature on lower feeding thresholds, gut evacuation rate, and diel feeding behavior in the copepod *Acartia hudsonica*. *Marine Ecology Progress Series*, 85: 93-106.

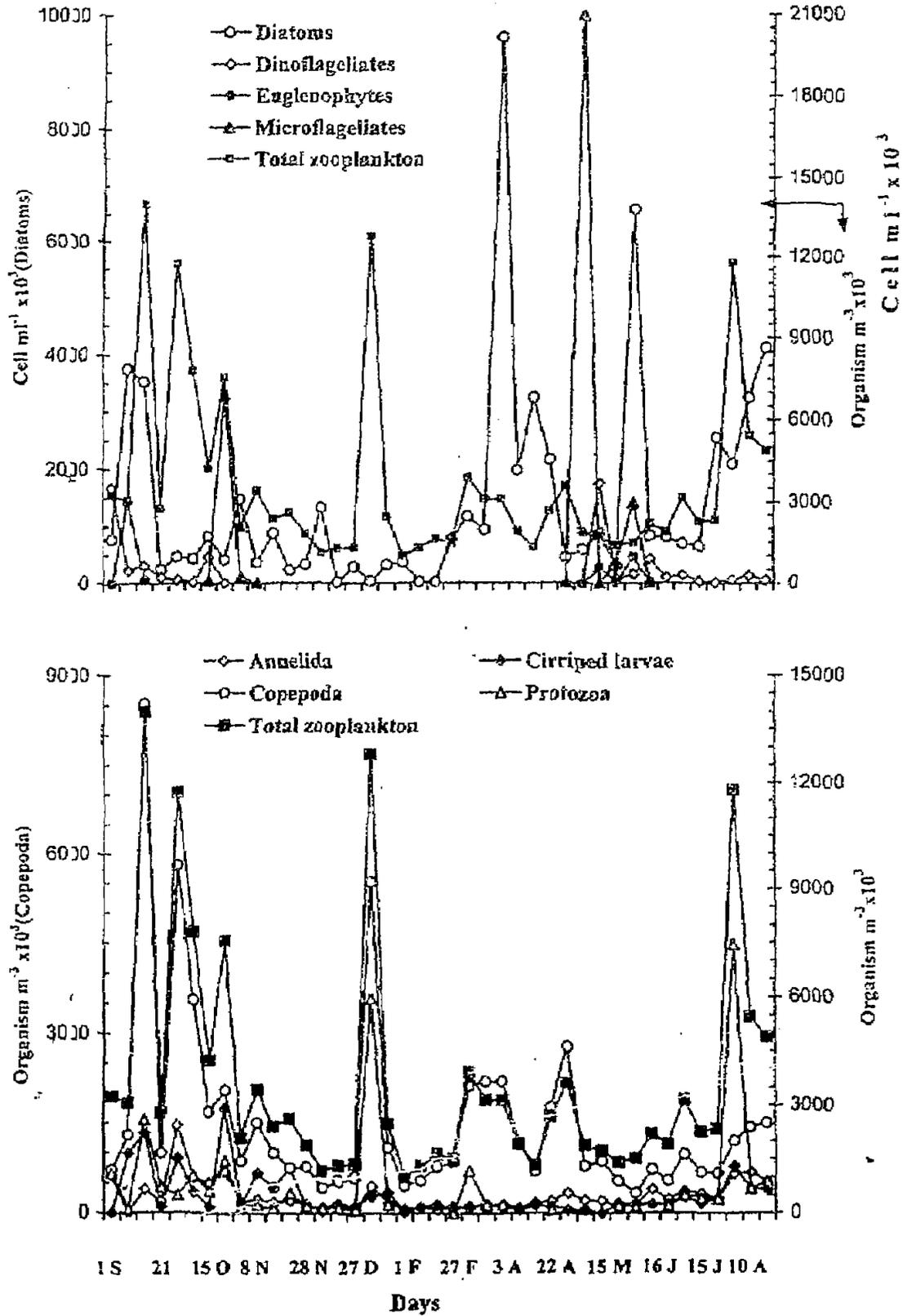


Figure 1. Major groups of phyto-zooplankton population.

PHYTO-ZOOPLANKTON COUPLING OFF ALEXANDRIA (EGYPT)

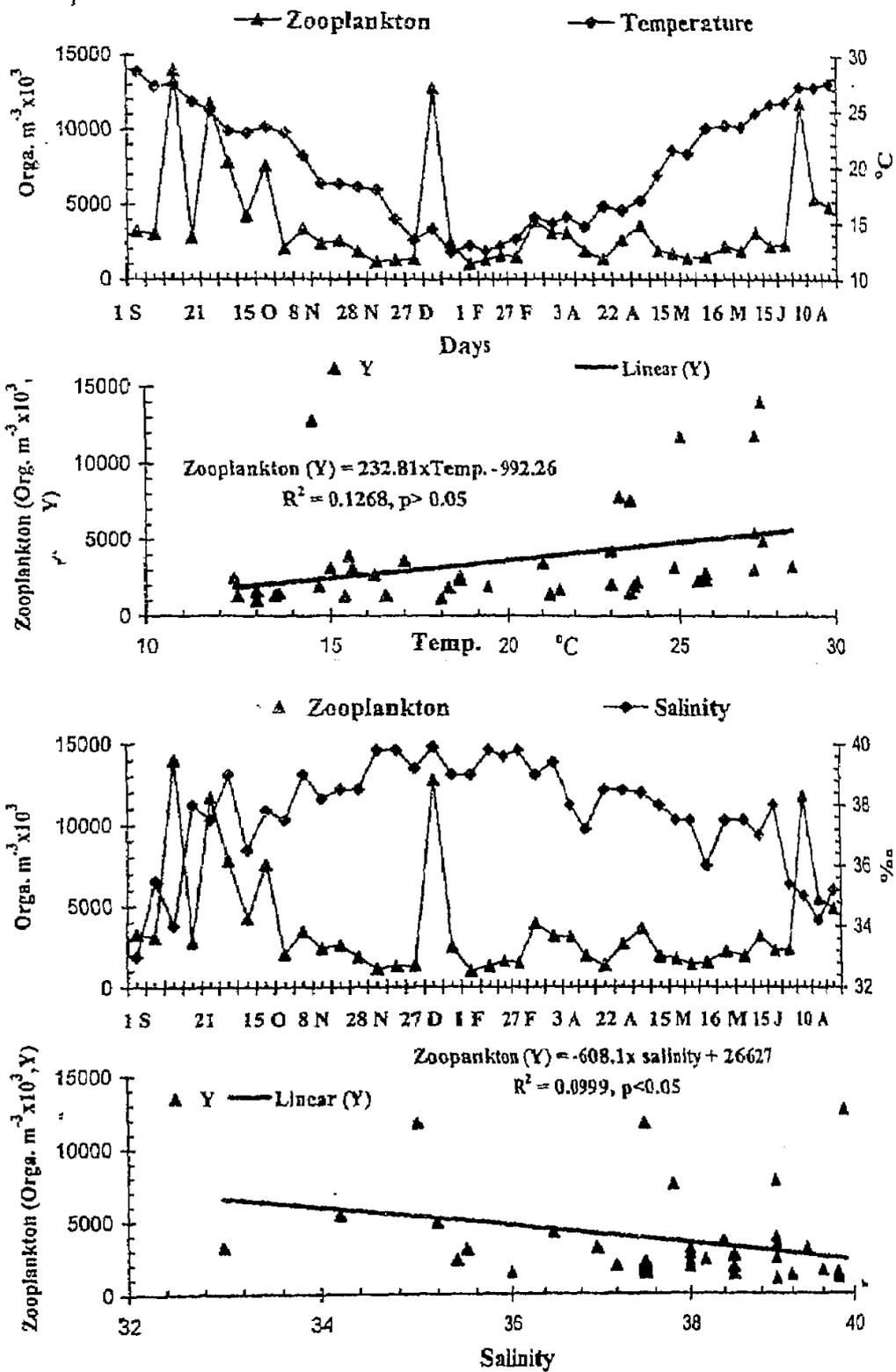


Figure 2. Zooplankton population, temperature, salinity and regression correlation

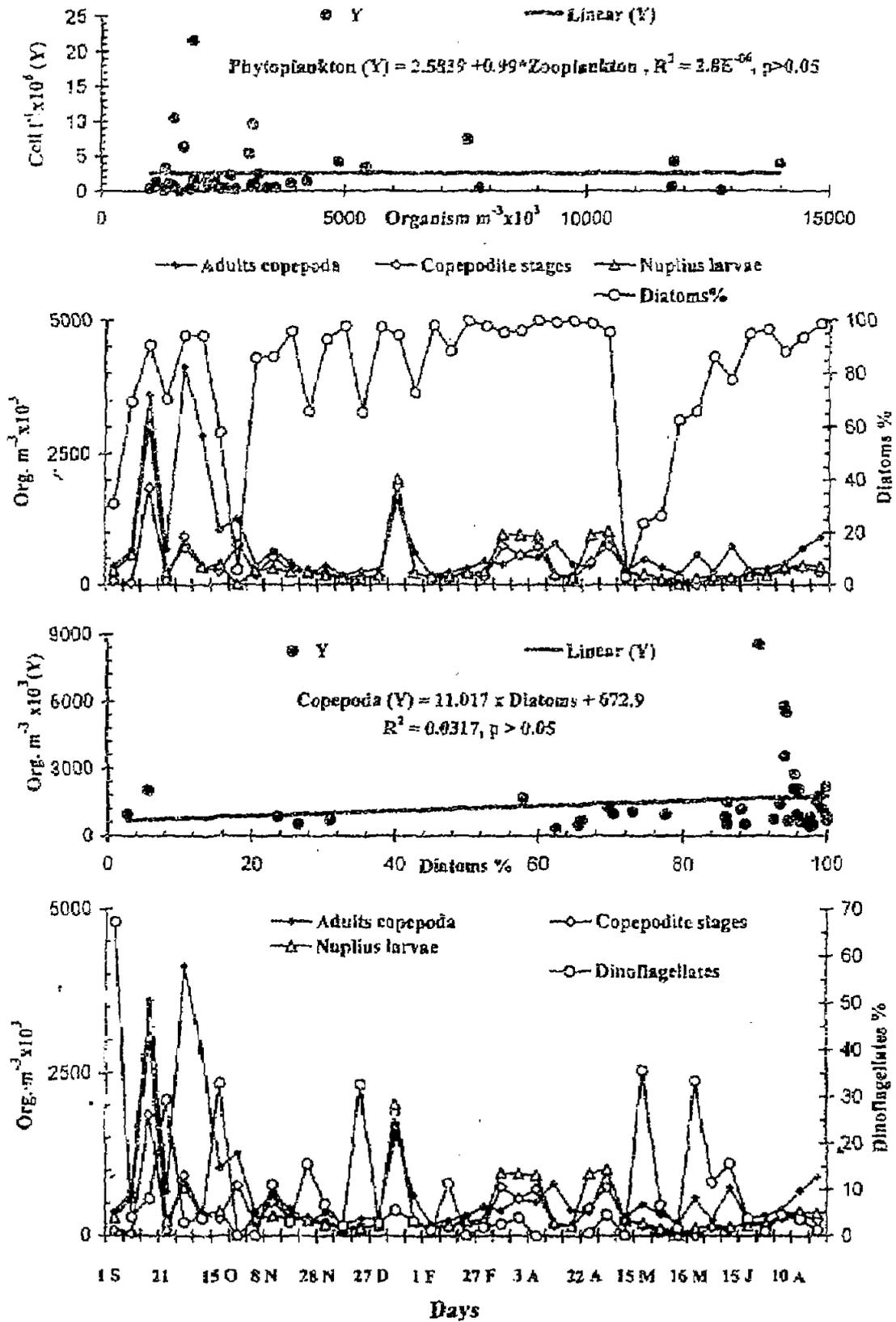


Figure 3. Phyto-zooplankton population and regression correlation

PHYTO-ZOOPLANKTON COUPLING OFF ALEXANDRIA (EGYPT)

Table 1: Matrix correlation coefficient

T	Sal	NO ₃	SiO ₄	PO ₄	S. c	Diat	D	Eu	Micr.	Z	An	C.1	Co	Os	Pro	Ro	A. c	C. s	
T	1.000																		
Sal	-0.820	1.000																	
NO ₃	-0.269	0.025	1.000																
SiO ₄	0.019	-0.248	0.364	1.000															
PO ₄	-0.237	-0.038	0.659	0.452	1.000														
S. c	0.175	-0.275	0.079	-0.045	1.000														
Diat	0.206	-0.416	0.397	0.145	0.188	1.000													
D	0.347	-0.439	0.213	0.306	0.083	0.146	1.000												
Eu	0.280	-0.284	0.249	-0.103	0.140	0.237	0.320	1.000											
Micr.	0.003	0.004	-0.185	-0.168	-0.199	0.833	-0.042	-0.074	1.000										
Z	0.356	-0.316	-0.188	0.313	0.273	0.002	0.060	-0.029	-0.057	1.000									
An	0.524	-0.384	-0.285	0.110	0.017	0.009	-0.060	0.148	-0.182	0.701	1.000								
C.1	0.361	-0.301	-0.128	0.065	0.144	0.108	0.087	-0.132	0.246	0.639	0.449	1.000							
Co	0.038	0.088	-0.083	0.146	0.285	-0.136	0.081	-0.067	-0.115	0.741	0.654	0.331	1.000						
Os	0.347	-0.241	-0.130	0.045	0.078	-0.164	-0.147	0.183	-0.131	0.615	0.796	0.285	0.592	1.000					
Pro	0.204	-0.222	-0.162	0.104	0.249	-0.008	-0.005	-0.039	-0.087	0.760	0.363	0.345	0.411	0.231	1.000				
Ro	0.081	-0.125	-0.115	0.084	0.148	0.174	0.278	-0.083	0.184	-0.138	-0.152	-0.088	-0.156	0.247	-0.088	1.000			
A. c	0.269	-0.183	-0.137	0.422	0.186	-0.072	-0.006	-0.016	-0.037	0.786	0.685	0.534	0.734	0.573	0.241	-0.157	1.000		
C. s	-0.043	-0.007	0.005	0.426	0.377	0.010	0.084	-0.131	-0.143	0.786	0.346	0.450	0.717	0.145	0.512	-0.080	0.648	1.000	
N. l.	0.074	-0.140	0.095	0.684	0.328	-0.015	0.195	-0.024	0.071	0.678	0.158	0.308	0.544	-0.007	0.426	0.001	0.581	0.885	1.000

T: Temperature SiO₄: Silicate Diat: Diatoms M: Microflagellates C.1: Cilioid larvae Prot: Protozoa
 Sal: Salinity PO₄: Phosphate D-Diat: Diatom flagellate Z: Total zooplankton Co: Copepoda Ro: Rotifera
 NO₃: Nitrate S. c: St. crop Eu: Euglena An: Annelida Os: Ostracoda
 Values under line: p < 0.05 C. s: Copepodite stages N. l.: Nuplius larvae A. c: Adult copepoda