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Effect of freshwater flow on the succession and abundance of phytoplankton in Rosetta Estuary, Egypt

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Abstract

Patterns in the spatial and temporal composition, dominance and abundance of the phytoplankton community in Rosetta Estuary were studied during one year at seven different sampling stations. A total of 152 taxa was recorded, of which Bacillariophyta (67 taxa) contributed the highest portion of the total number of taxa, followed by Chlorophyta (41 taxa), Cyanophyta (18 taxa) and Dinophyta (16 taxa). The main phytoplankton associations were characterized by green algae and diatoms, in distinctive patterns of dominance. Fresh and marine water fluxes are responsible for phytoplankton heterogeneity. There is a gradual reduction in phytoplankton abundance towards the mouth of the estuary. The inner stations showed two bloom periods; the first in spring and the other in winter, both associated with low water salinities resulting from discharge of fresh Nile water into the estuary. The phytoplankton dynamics of the outer stations were characterized by highly spatial variable system.

Species diversity ranged from 0.3 to 3.37, with the highest index in May. Phytoplankton standing crop was observed to have a negative effect on species diversity.

Scenedesmus, *Selenastrum*, *Actinastrum*, *Crucigenia*, *Cyclotella*, *Nitzschia* and *Skeletonema* were possibly the most prevalent phytoplankton genera in the estuary at different periods.

The similarity analysis demonstrated two assemblages, the first one appeared in the outer stations with similarity of 60-72%, and the inner stations with similarity 72-80%. The inner stations had pronouncedly high annual average counts and were characterized by more chlorophytes occurrence, reached >63% at stations 5 and 6, and the less productive outer stations, by the appearance of brackish water species of dinophytes (32%, at station 3).

Keywords: Rosetta Estuary, phytoplankton, species succession, diversity, salinity.

INTRODUCTION

An estuary is a semi-enclosed coastal body of water with a free connection to the open sea and within which seawater is diluted by freshwater [1]. The continuous exchange between estuaries and the open sea allows rapid changes in salinity, temperature and nutrients. This variability has strong effects on both the composition and the dynamics of the biota [2].

Rosetta estuary lies at the lower reach of Rosetta Branch. It is partially isolated from the River Nile by the construction of a barrage. The Nile water in front the barrage is maintained at a constant level, not exceeding 2.9 m above mean sea level.

The estuary is 42 km long from the barrage to the outlet at the Mediterranean Sea. Its width varies between about 300 and 850 m, with an average of 600 m. The bottom topography of the estuary is irregular, presenting a succession of depressions, the middle one reaches 18 m in depth. The sill depth at the outlet rises to about 6 m from the surface.

Salinity is known to be a structuring mechanism for the phytoplankton composition, since estuaries and coastal areas provide a transition zone between freshwater and marine species [3]. However, there can be between ecosystems large differences in the phytoplankton composition versus salinity. Although salinity can explain some of the changes in the phytoplankton community of estuaries, it cannot account for all spatial variation [4]. Moreover, turbulent waters are known to favour large phytoplankton [5,6], which may also affect the phytoplankton composition in relation to typology, particularly if the tidal influence is large.

Few investigations were carried out dealing with the distribution of phytoplankton in Rosetta estuary [7-9]. The objective of this study was to investigate the succession, annual cycle and diversity of the phytoplankton community in Rosetta Estuary over a wide range of variable water salinity.

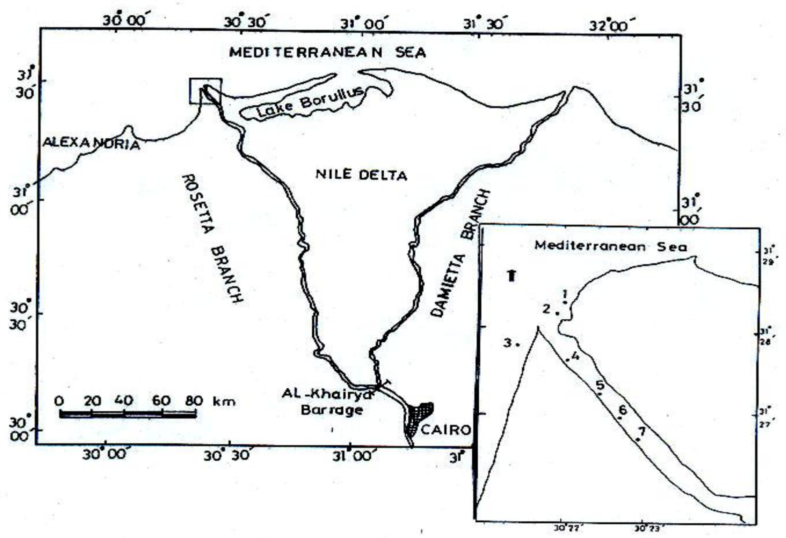

Figure 1: Study area and sampling stations.

Fig. 1. Study area and sampling stations.

MATERIALS AND METHODS

Samples were collected at monthly intervals between February 2004 and January 2005 from seven fixed stations. The study included the end portion of Rosetta Branch at the connection with the Mediterranean Sea (Fig. 1). Samples were persevered with

Lugol's solution and analysed according to Utermöhl method [10]. The identification of phytoplankton species was according to the most known literatures [11-18].

Temperatures were measured by an ordinary thermometer and salinity was measured argentometrically.

Two indices were used to obtain the estimate of species diversity. These are species richness [19] and Shannon-Wiener diversity index (H') [20]. Species equitability or evenness (J') was calculated according to Pielou method [21]. The cluster analysis of Cormack [22] was used to distinguish the groups of stations on basis of abundance of phytoplankton species. Grouping of phytoplankton species in terms of frequency coefficient was used following frequency groups to show the presence frequency of species in the community during the year. Frequency groups: 1-20%, 21-40%, 41-60%, 61-80% and 81-100% for rare, common, abundant, very abundant and continuous (existent throughout the year) species in the community, respectively. Frequency was calculated with the following equation: $f = Na : Nn \times 100$ (Na: presence number of species A in total sampling or individual number of A species; Nn: total number of sampling or total individual number of whole species).

RESULTS

Water temperature did not deviate from the normal seasonal fluctuations on the Egyptian coastal waters (13-32°C), as shown in Fig. 2. The lowest values were recorded during winter (13-19°C) and the highest in summer (26-32°C), with an average amplitude of 17°C. Seasonal average temperature showed a gradual increase from winter (16.2°C) to spring (25.1°C) to summer (28.2°C) followed by a sharp decrease during autumn (20°C).

The variations in water salinity reflected the interaction between fresh Nile water and saline Mediterranean Sea. Stations 1, 2 and 3, lying at the east, middle and west of the estuarine mouth had annual average salinity 23.5 PSU (station 2) to 33.0 PSU (station 3), respectively. The inner stations (4-7) sustained lower average salinity ranging from 13.1 PSU (station 7) to 16.3 PSU (station 4). Excluding station 3, which usually had high salinity, lowest values were recorded in May and January, reaching < 2.8 PSU (Fig. 3).

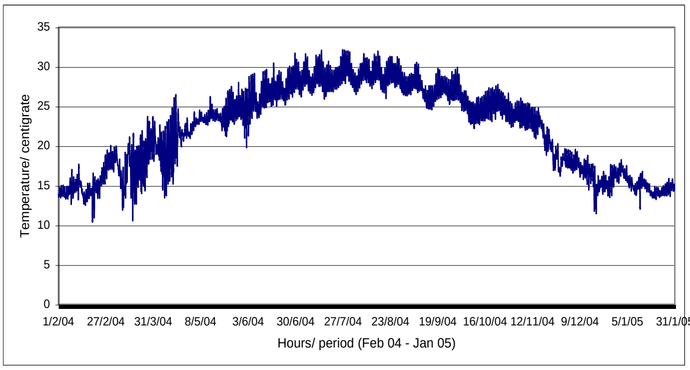

Fig. 2 Temperature change time series for Rosetta Esluary

Figure 2: Temperature change time series for Rosetta Esluary.

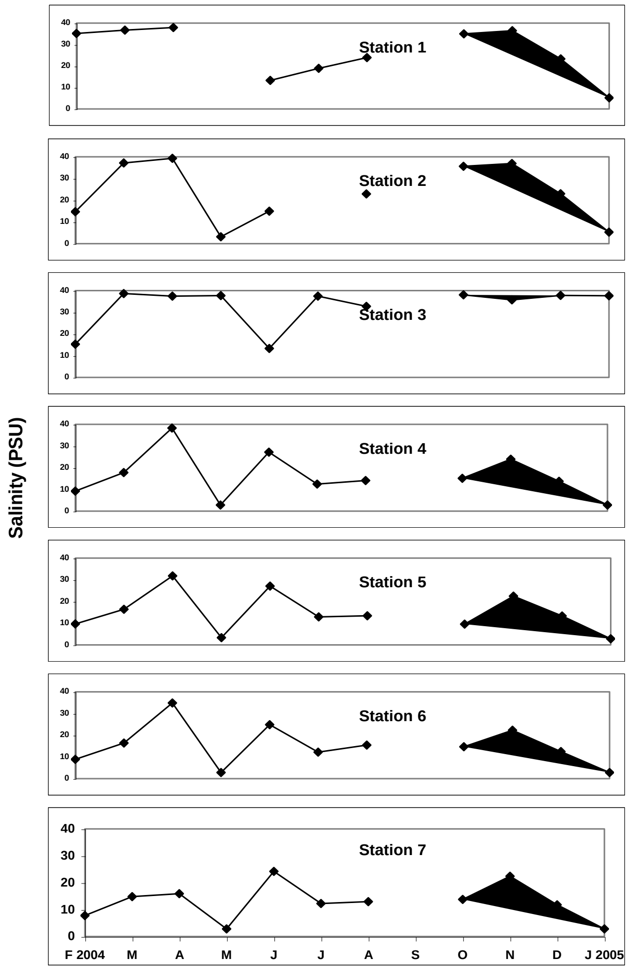

Figure 3: Monthly changes in surface water salinity at sampling stations.

Species composition and community structure

Hundred and fifty two species of phytoplankton were recorded during the period of investigation (Table 1). There were some brackish, euryhaline and eurythermal species. There were also many species of high salinity.

As it is usually found in estuarine region; Bacillariophyceae comprised the highest number of taxa (31 genera, 67 spp.), but Dinophyceae showed remarkably low number (10 genera, 16 spp). The freshwater Chlorophyceae, Cyanophyceae and Euglenophyceae were represented by 41, 18 and 8 species, respectively. Rhodophyceae and Dictyochophyceae classes were represented by only one species each (Table 2).

The total number of species at the sampled stations reflected high similarity of phytoplankton composition (Table 3). The frequency of appearance for different species revealed that 48 species were observed throughout the whole area, 18 species were observed at 6 stations, 15 species at 5 stations, 16 species at 4 stations, 17 species at 3 stations, 18 species at 2 stations and 20 species were restricted to only one station, regardless of great differences in their densities among stations.

According to the results of frequency coefficient in the community structure of the phytoplankton species, 46 taxa (30.5% of total 152 taxa) were rare (frequency group of 1-20%), 28 taxa (18%) were common, 37 taxa (24.5%) were abundant, 13 taxa (9%) were very abundant, and 28 taxa (18%) were continuous species.

Table 1: Species list and temporal variations of phytoplankton in Rosetta Estuary between February 2004 and January 2005 (1-20%α rare, 21-40%α common, 41-60%α abundant, 61-80%α very abundant, 81-100%α continuous species, +: present, -: absent, q: quantitatively important).

Table 1. Species list and temporal variations of phytoplankton in Rosetta Estuary between February 2004 and January 2005 (1-20%: rare, 21-40%: common, 41-60%: abundant, 61-80%: very abundant, 81-100%: continuous species, +: present, -: absent, q: quantitatively important).

Species	Months												
	F	M	A	M	J	J	A	S	O	N	D	J	F (%)
Bacillariophyceae													
Achnanthes brevipes Ag.	-	+	+	+	-	-	-	+	+	+	+	+	67
Achnanthes longipes Ag.	+	+	+	-	+	+	+	+	+	+	+	-	83
Achnanthes parvula kutz	-	-	-	-	-	+	+	+	+	+	+	-	50
Amphora ovalis kutz	-	-	-	+	+	-	+	-	+	-	+	+	50
Amphiprora paludosa Wm.Sm.	-	-	-	-	-	-	-	-	+	-	+	+	25
Asterionella japonica Cleve & O.F. Mull.	+	+	-	-	-	-	-	-	-	+	-	-	25
Asterolampra sp.	-	+	-	+	-	-	-	-	-	-	-	-	17
Bacillaria paradoxa G.F.Gmel.	+	-	-	+	+	+	-	-	+	+	+	+	67
Bacteriastrum hyalinum Lauder	-	-	-	-	-	-	-	-	-	+	-	-	8
Biddulphia alternans (Bail), H.V.H.	+	+	+	+	-	-	+	+	-	+	-	-	58
Biddulphia laevis Ehr.	-	-	+	-	-	-	+	+	-	-	+	-	33
Biddulphia mobiliensis Bail. Grun.	+	+	+	-	-	+	-	-	-	+	-	+	50
Biddulphia rhombus (Ehr), Wm.	-	-	+	-	-	-	-	-	-	+	-	-	17
Biddulphia smithu (Ralfs) H.V.H.	+	-	+	-	-	+	-	+	-	+	-	+	50
Chaetoceros sp.	+	-	-	-	-	-	-	-	+	+	-	-	25
Cocconeis placentula Ehr.	+	+	+	+	-	-	-	-	+	-	+	+	58
Coscinodiscus sp.	-	-	-	-	-	-	+	+	-	+	-	-	25
Cyclotella comta (Ehr.), Kutz.	-	-	-	-	-	-	+	-	-	-	+	-	17
Cyclotella meneghiniana kutz q	+	+	+	+	+	+	+	+	+	+	+	+	100
Cymbella lanceolata Ehr.	+	+	+	+	+	+	+	+	+	+	+	+	100
Cymbella turgida Greg.	+	-	-	+	+	+	+	+	+	+	+	-	75
Epithemia zebra (Ehr.), Kutz	-	-	-	+	-	-	-	-	-	-	-	-	8
Grammatophora angulosa Ehr.	-	-	+	-	-	-	-	-	-	-	-	-	8
Gomphonema olivaceum Lyngb.	-	-	-	+	+	+	+	+	+	+	+	-	67
Hantzschia marina (Donkin) Grun.	+	-	-	-	-	-	-	-	-	+	-	-	17
Hemiaulus haucku Grun.	-	+	+	-	-	-	-	-	+	-	-	-	25
Lauderia borealis Grun.	+	-	-	-	-	-	-	-	-	-	-	+	17
Licmophora gracilis (Ehr.), Grun.	-	+	+	+	+	+	+	-	-	+	+	+	75
Melosira crucipunctata Bachm.	-	-	-	+	-	-	-	-	-	-	-	+	17
Melosira granulata (Ehr.), Ralfs	+	-	+	+	-	-	-	-	+	+	-	+	50
Melosira jurgensu Ag.	-	-	-	-	-	-	-	-	-	-	+	+	17
Navicula borealis Ehr.	+	-	+	+	+	+	-	+	+	+	+	+	83
Navicula cryptocephala kutz.	+	+	+	+	+	+	+	+	+	+	+	+	100
Navicula didyma Ehr.	-	-	+	+	+	+	-	+	-	+	+	-	58
Navicula globiceps Greg.	-	-	-	-	-	-	-	-	-	+	-	-	8
Navicula gracilis kutz.	+	+	+	+	+	+	+	+	+	+	+	+	100
Navicula gregaria Donk.	-	+	-	-	-	-	-	+	+	+	+	+	50
Navicula humerosa Breb.	-	-	-	+	+	+	-	-	-	-	-	-	25
Navicula mutica kutz	+	+	+	+	+	-	+	+	+	+	+	+	92
Navicula opima Grun.	-	+	-	-	+	+	-	+	+	+	+	-	58
Navicula placentula Ehr.	-	+	+	+	+	+	+	+	+	+	+	-	83
Nitzschia acicularis Wm.Sm.	-	-	-	+	+	+	-	-	-	-	+	-	33
Nitzschia apiculata (Greg.), Grun.	+	-	+	+	+	+	-	+	-	+	+	+	75
Nitzschia closterium W.Sm.	-	+	-	+	+	+	+	+	+	+	+	+	83
Nitzschia frustulum (kutz), Grun.	+	+	+	+	+	+	-	+	+	+	+	+	92
Nitzschia longissima (Breb.) Ralfs.	-	-	-	-	-	-	-	-	-	+	-	-	8

Table. (Continued)

Species	Months												
	F	M	A	M	J	J	A	S	O	N	D	J	F
Nitzschia microcephala Grun.	+	+	+	+	+	+	+	+	+	+	+	+	100
Nitzschia obtusa Wm. Sm.	-	-	-	-	-	-	+	+	-	-	+	+	33
Nitzschia palea (Kutz) Wm. q	+	+	+	+	+	+	+	+	+	+	+	+	100
Nitzschia punclata (Wm.Sm.), Grun.	-	-	-	-	-	-	+	-	-	-	+	-	17
Nitzschia sigma Wm.Sm.	+	+	+	+	+	+	+	+	+	+	+	+	100
Nitzschia tryblionella Hantzsch.	+	-	-	+	-	-	-	+	-	-	-	-	25
Pleurosigma elongatum W. Smith	+	-	-	+	+	+	-	+	-	+	-	-	50
Pleurosigma macrum Wm. Sm.	-	-	-	+	-	-	-	-	-	-	-	-	8
Podosira stelliger (Baily) Mann.	-	-	-	+	-	-	-	-	+	+	-	+	33
Rhizosolenia alata Bright	-	-	-	-	-	-	-	-	+	+	-	-	17
Rhizosolenia setigera Bright.	-	-	-	-	-	-	-	-	-	+	+	-	17
Rhizosolenia stolterfothu H. Perag.	-	-	-	-	-	-	-	-	-	+	-	-	8
Rhizosolenia styliformis Bright.	-	-	-	-	-	-	-	-	-	+	-	-	8
Skeletonema costatum (Grev.) Cl. q	+	+	+	-	-	+	-	-	+	+	+	-	58
Synedra nitzschioides Grun.	-	+	+	+	+	+	-	+	+	+	+	+	83
Synedra rumpens kutz.	-	-	-	-	-	-	-	-	-	-	+	-	8
Synedra tabulata kutz	+	-	-	+	-	-	-	+	-	+	-	-	33
Synedra ulna (Nitzsch.), Ehr.	+	+	+	+	-	-	-	-	+	-	+	+	58
Thalassionema nitzschioides Hust.	-	-	-	+	-	+	-	-	-	+	-	-	25
Thalassiosira decipiens (Grun). C. Jorg.	+	-	-	-	-	-	-	-	-	-	+	-	17
Thalassiothrix frauenfedu Grun.	-	-	-	-	-	-	-	-	-	+	-	-	8
Chlorophyceae													
Actinastrum hantzschu Lagerh. q	+	-	-	+	-	-	-	-	-	+	+	+	42
Ankistrodesmus falcatus (Corda) Ralfs.	+	+	+	+	+	-	+	+	+	+	+	+	92
Ankistrodesmus fusiformis Corda	+	-	-	+	-	-	-	-	-	-	-	+	25
Ankistrodesmus spiralis (Turner) Lemm.	-	-	-	+	-	+	-	-	-	+	-	+	33
Ankistrodesmus setigerus (Schrod) G.S. west.	-	+	+	+	+	+	-	+	+	+	+	+	83
Carteria globosa korsch.	+	-	-	+	-	+	+	+	-	-	+	+	58
Characium acuminatum A. Braun	+	+	+	+	-	+	-	+	+	+	+	+	83
Chlamydomonas ovalis Pasch.	-	-	-	-	-	-	-	-	-	-	+	-	8
Chlorella vulgaris Beier.	-	+	+	+	+	+	+	+	+	-	+	+	83
Closterium acutum Breb.	-	+	+	+	+	-	+	-	-	-	-	+	50
Coelastrum microporum Naeg.	-	-	-	+	-	-	-	-	-	-	-	+	17
Cosmarium galeatum W. & G.S. West.	-	-	-	-	-	-	-	-	+	-	-	-	8
Crucigenia rectangularis (A.Braun) Gayq	+	+	-	+	+	-	+	+	+	+	+	+	83
Crucigenia tetrapedia (Kirch)W.et west.	-	-	-	+	+	-	-	+	+	+	+	+	58
Crucigenia quadrata Morren.	+	-	-	+	-	-	+	+	+	-	+	+	58
Gloeocystis gigas (kutz) Lag.	-	-	-	+	-	-	-	-	-	+	+	-	25
Kirchneriella contorta (Schm.) Boh.	+	+	+	+	+	+	+	+	+	+	+	+	100
Kirchneriella lunaris (kirch) Moeb.	+	-	-	+	+	-	-	+	+	+	+	+	67
Micractinium radiatum (Chodat) wille.	+	-	-	+	-	-	-	-	-	-	-	-	17
Micractinium pusillum Fresen.	-	-	-	+	-	-	-	-	-	-	-	+	17
Oocystis borgei Snow.	-	-	-	+	-	-	-	-	-	-	-	+	17
Oocystis solitaria Wittr.	-	-	-	+	-	-	-	-	-	-	-	-	8
Pediastrum clathratum (A. Braun) Lag.	-	-	+	+	-	-	-	-	+	-	-	-	25
Pediastrum duplex Meyen.	-	-	-	+	-	-	-	-	-	-	-	+	17
Pediastrum simplex Meyen.	+	-	-	+	-	-	-	+	-	+	-	+	42
Planktosphaeria gelatinosa G.M. Smith.	-	-	-	+	-	-	-	-	-	-	-	+	17
Scenedesmus acuminatus (Lagerh)Chodat.	-	-	-	+	-	-	-	-	-	-	-	+	17
Scenedesmus arcuatus (Lemm.) Lemm.	-	+	-	+	-	-	-	-	-	-	-	+	25
Scenedesmus bijugatus (Turp.) Kutz.	+	-	-	+	+	-	-	+	+	-	-	+	50
Scenedesmus dimorphus Turp.	-	+	-	+	+	-	-	-	-	-	-	+	33
Scenedesmus obliquus (Turp.) kutz.	-	-	-	+	+	-	-	-	-	+	+	+	42
Scenedesmus quadricauda (Turp.) Breb.q.	+	+	+	+	+	-	+	+	+	+	+	+	92
Schroederia sp.	+	+	+	+	+	+	+	+	+	-	-	-	75
Selenastrum gracile Reinsch. q	+	-	-	+	+	+	+	+	+	+	+	+	83
Sphaerocystis schroeteri Chodat.	-	+	-	+	-	-	+	-	-	-	-	+	33

Table. (Continued)

Species	Months												
	F	M	A	M	J	J	A	S	O	N	D	J	F
Staurastrume tetracerum Ralf.	-	-	-	+	-	-	-	-	-	-	-	+	17
Tetrachlorella alternans Beijer.	-	-	-	+	-	-	-	-	-	-	-	-	8
Tetraedron caudatum (Corda) Hansg.	-	-	-	+	+	-	-	-	-	-	-	+	25
Tetraedron minimum (A. Braun) Hansg.	-	+	-	+	+	+	-	+	-	-	+	+	58
Tetraedron muticum A. Braun.	+	-	-	+	-	+	+	+	-	-	+	+	58
Tetraedron proteiforme (Turn) Braun.	-	-	-	+	+	-	-	-	-	-	-	-	17
Cyanophyceae													
Anabaena circinalis Rabh.	-	-	-	-	+	-	-	-	-	-	+	-	17
Anabaenopsis circularis (G.S. West) Wol. &	-	-	-	-	-	-	-	-	+	-	-	-	8
Anabaenopsis flos-aquae (Lyngb.) Breb.	+	-	-	-	-	-	-	-	-	-	-	-	8
Aphanocapsa delicatissima W. et G.S. West.	-	-	-	+	-	-	-	+	-	-	-	+	25
Chroococcus dispersus (Kelssl.) Lemm.	-	+	-	+	-	-	-	-	+	-	+	+	42
Chroococcus minutus (Kg.) Naeg.	+	-	-	+	+	-	+	+	-	-	-	+	50
Dactylococcopsis acicularis Lemm.	+	+	+	+	+	+	+	+	+	-	+	+	92
Dactylococcopsis irregularis G.M. Smith.	+	+	+	+	-	+	-	+	-	-	+	+	67
Lyngbya limnetica Lemm.	+	-	-	+	+	+	-	+	+	+	-	-	58
Oscillatoria brevis (Kg.) Gom.	-	-	+	+	+	+	+	-	+	-	+	-	58
Oscillatoria irrigua Kg.	-	+	+	+	+	+	+	+	-	+	-	+	75
Oscillatoria limnetica Lemm.	-	+	-	+	+	+	+	+	+	+	+	+	83
Oscillatoria tenius Agardh.	+	+	+	+	+	+	+	+	+	-	+	-	83
Oscillatoria princeps Vauch.	+	-	+	-	-	-	+	-	-	+	+	-	42
Merismopedia punctata Lemm.	-	-	+	+	+	-	-	-	+	-	-	-	33
Microcystis aeruginosa Kg.	-	-	-	+	+	-	-	+	-	-	-	+	33
Spirulina laxissima G.S. West.	-	-	-	-	+	+	-	-	-	-	-	-	17
Spirulina platensis (Nordst) Gei.	-	-	-	+	-	-	-	-	-	-	-	-	8
Dinophyceae													
Ceratium furca (Ehr.) Clap. & Lach.	-	-	-	+	+	+	-	+	-	-	-	-	42
Ceratium fusus (Ehr.) Dujar	-	-	-	-	-	-	-	+	-	-	-	-	8
Dinophysis caudata Saville-Kent.	-	+	+	-	+	-	-	-	-	-	-	-	25
Exuviella compressa Ostenfeld	+	+	+	+	+	+	+	+	+	+	+	-	92
Oxytoxum sceptrum (Stein) Sch.	+	+	+	-	+	-	-	-	-	+	+	-	50
Goniaulax conjuncta Wood.	-	-	-	-	+	-	-	-	-	-	-	-	8
Gonyaulax polygramma Stein.	+	+	-	-	-	+	+	+	-	-	-	-	42
Gymnodinium sp.	+	-	+	+	+	+	+	+	-	+	+	-	75
Gyrodinium falcatum Kofoid & Swezy.	-	-	-	-	+	-	-	+	-	-	-	-	17
Prorocentrum micans Ehrenb.	+	+	+	+	+	+	+	+	+	+	+	+	100
Prorocentrum triestinum Schiller.	-	-	+	+	+	+	+	-	-	-	-	-	42
Protoperidinium conicum Gran.	+	+	+	+	+	-	+	+	+	+	+	-	83
Protoperidinium cerasus (Paulsen) Balech.	-	+	-	-	+	-	-	-	+	-	-	-	25
Protoperidinium conicoides (Paulsen) Baled.	+	+	+	+	+	+	+	-	-	+	-	-	67
Protoperidinium depressum (Bailey) Balech.	-	+	+	-	+	-	+	-	-	-	-	-	33
Protoperidinium trochoideum (Stein) Lemm.	+	-	-	+	+	+	+	+	-	+	-	-	58
Euglenophyceae													
Euglena acus Ehr.	+	+	+	+	+	+	+	-	-	+	+	-	75
Euglena caudata Hubner.	+	-	+	-	+	+	+	-	-	-	-	-	42
Euglena ehrenbergii Klebs.	-	+	-	-	-	-	+	-	-	+	-	-	25
Euglena granulata (Klebs.) Lemm.	+	-	-	-	+	+	-	-	+	+	+	-	50
Euglena klebsu Delf.	-	-	-	-	-	-	-	-	-	+	-	-	8
Euglena spirogyra Ehr.	+	+	+	+	+	-	-	-	+	-	-	-	50
Phacus pyrum (Ehr.) Stein.	-	-	-	+	-	-	+	-	-	-	-	-	17
Phacus triqueter (Ehr,) Duj.	-	-	-	+	-	-	-	-	-	-	-	-	8
Rhodophyceae													
Compsopogon caeruleus Mont.	-	-	-	-	-	+	+	-	-	-	-	-	17
Dictyochophyceae.													
Dictyocha fibula Ehr.	-	-	-	-	+	+	+	+	+	+	-	-	50

Diatoms and green algae were more abundant both qualitatively (71.1%) and quantitatively (93.6%) than the other taxonomic groups. They were conspicuous as the two most diverse groups with 44.1 and 27% in the total species number, respectively, although diatoms and green algae were almost equally in the quantitative proportion (45% and 48.6%, respectively) (Table 2).

Despite of the limited spatial variations (91-105 species), pronounced temporal differences were observed in number of species, whereas 56-100 species appeared monthly at the estuarine region (Table 4). The temporal variation in the number of species is related to seasonal succession as well as to the growth pattern of different species in the community structure. Diatoms were more diversified in late spring (May) and autumn (November – December) than in other periods. However, chlorophytes were more diversified in May and January. Dinophytes showed greatest numbers of species in June, while cyanophytes, in May and June. Maximum and minimum numbers of species were recorded in May (100 spp.) and March-April (56 spp.), respectively (Table 4).

Table 2. Taxonomic composition and proportional representation of the phytoplankton groups in Rosetta Estuary between February 2004 and January 2005.

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Group	Genus	Species	%	Unit l^{-1}	%
Bacillariophyceae	31	67	44.1	99465	45.0
Chlorophyceae	23	41	27.0	107414	48.6
Dinophyceae	10	16	10.5	7463	3.4
Cyanophyceae	10	18	11.8	6145	2.8
Euglenophyceae	2	8	5.2	309	0.2
Rhodophyceae	1	1	0.7	83	0.0
Silicoflagellates	1	1	0.7	79	0.0
Total	78	152	100	220958	100

Table 3: Number of species of different group at the sampled stations.

Table 3. Number of species of different groups at the sampled stations

Table 3. Number of species of different groups at the sampled stations

group \ station	1	2	3	4	5	6	7
Bacillariophyceae	41	42	45	40	43	45	36
Chlorophyceae	26	31	24	32	29	31	33
Dinophyceae	12	12	11	14	9	10	9
Cyanophyceae	9	13	11	11	13	14	14
Euglenophyceae	2	3	3	4	7	4	4
Rhodophyceae	-	-	-	-	1	1	-
Silicoflagellates	1	1	1	-	-	-	-
Total	91	102	95	101	102	105	96

Stations 1,2 and 3 had pronouncedly low annual average counts (48 x 10^3, 102 x 10^3 and 20 x 10^3 units l^{-1}, respectively). On the other hand, the inner stations were more productive, fluctuated between 243 x 10^3 units l^{-1} at station 5 and 506 x 10^3 units l^{-1} at station 4. Low salinity species from Rosetta Nile branch become the main part of communities in the estuary.

The dominant phytoplankton species were determined as species occupied more than 1% of total counts and were used for identifying species assemblages. Two major assemblages I and II were obtained at 60% of the index (Fig. 4). The assemblage I distributed on the outer stations (1, 2, 3), which mainly subjected to seawater and assemblage II represented by the inner stations with less water salinity; each referred as the outer and inner stations community, respectively. Seven most dominant species in each assemblage were listed in Table 5, as determined by average relative abundance species to total count in each side. The outer community was characterized by marine euryhaline species and the inner community was dominated by mainly freshwater species.

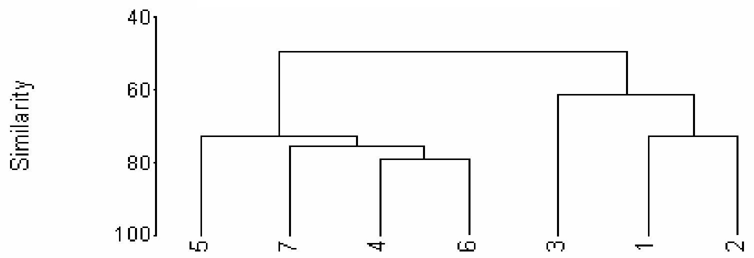

Figure 4: Dendrogram for the percent similarity index of phytoplankton samples prepared by the cormack method.

Fig. 4. Dendrogram for the percent similarity index of phytoplankton samples prepared by the Cormack method.

Table 4: Number of species and percentage composition of the taxonomic group in phytoplankton in Rostta Estuary

Table 4. Number of species and percentage composition of the taxonomic groups in phytoplankton in Rostta Estuary

Taxonomic Group	Sampling period													
	February 2004		March		April		May		June		July		August	
	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Bacillariophyceae	29	45.3	25	44.6	28	50.0	36	36.0	25	34.7	28	47.5	22	37.9
Chlorophyceae	16	25	13	23.2	9	16.1	39	39.0	17	23.6	10	16.9	13	22.4
Dinophyceae	8	12.5	9	16.1	9	16.1	8	8.0	14	19.4	8	13.6	10	17.2
Cyanophyceae	7	10.9	6	10.7	7	12.5	13	13.0	11	15.3	8	13.6	7	12.2
Euglenophyceae	4	6.3	3	5.4	3	5.3	4	4.0	4	5.6	3	5.0	4	6.9
Rhodophyceae	-	-	-	-	-	-	-	-	-	-	1	1.7	1	1.7
Dictyochophyceae	-	-	-	-	-	-	-	-	1	1.4	1	1.7	1	1.7
Total	64	100	56	100	56	100	100	100	72	100	59	100	58	100

Table 4. (continued)

Taxonomic Group	Sampling period											
	September		October		November		December		January 2005		Total	
	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Bacillariophyceae	30	46.9	31	49.2	46	61.3	38	53.5	29	41.4	67	44.1

Rhodophyceae	-	-	-	-	-	-	-	-	-	-	1	1.7	1	1.7
Dictyochophyceae	-	-	-	-	-	-	-	-	1	1.4	1	1.7	1	1.7
Total	64	100	56	100	56	100	100	100	72	100	59	100	58	100

Table 4. (continued)

Taxonomic Group	**Sampling period**											
	September		**October**		**November**		**December**		**January 2005**		**Total**	
	no.	**%**	**no.**	**%**	**no.**	**%**	**no.**	**%**	**no.**	**%**	**no.**	**%**
Bacillariophyceae	30	46.9	31	49.2	46	61.3	38	53.5	29	41.4	67	44.1
Chlorophyceae	16	25.0	16	25.4	13	17.4	18	25.4	32	45.7	41	27.0
Dinophyceae	7	10.9	6	9.5	7	9.4	5	7.0	1	1.4	16	10.5
Cyanophyceae	10	15.6	7	11.1	4	5.3	8	11.3	8	11.5	18	11.8
Euglenophyceae	-	-	2	3.2	4	5.3	2	2.8	-	-	8	5.2
Rhodophyceae	-	-	-	-	-	-	-	-	-	-	1	0.7
Dictyochophyceae	1	1.6	1	1.6	1	1.3	-	-	-	-	1	0.7
Total	64	100	63	100	75	100	71	100	70	100	152	100

Table 5: Dominant species and their mean relative abundance in total cell number in the assemblages, I and II as identify by the cluster analysis.

Table 5. Dominant species and their mean relative abundance in total cell number in the assemblages, I and II as identified by the cluster analysis

Species	**Relative abundance**
Assemblage I	
Prorocentrum triestinum	4.4
Biddulphia alternans	2.5
Protoperidinium conicum	2.4
Exuviella compressa	2.2
Nitzschia microcephala	1.3
Asterionella japonica	1.2
Licmophora gracilis	1.1
Assemblage II	
Schroederia sp.	11.1
Ankistrodesmus setigerus	7.9
Ankistrodesmus fusiformis	1.4
Melosira granulata	1.4
Sphaerocystis schroeteri	1.1
Synedra ulna	1.1
Pediastrum simplex	1.0

Other seven predominant species showed strongly distribution along the sampled stations, as *Scenedesmus quadricauda*, (5.9%), *Selenastrum gracile* (4.2%), *Actinastrum hantzschii* (8.5%), *Crucigenia rectangularis* (1.8%), *Cyclotella meneghiniana* (4.0%), *Nitzschia palea* (5.3%) and *Skeletonema costatum* (24.0%).

Several of the dominant species, either marine or freshwater demonstrated different tolerance ranges to salinity variations (Table 6). The marine diatom *Biddulphia alternans*, as well as the freshwater chlorophytes *Crucigenia rectangularis* can withstand the widest salinity variations (14.7-38.6 and 2.0-38.0 PSU, respectively). Other marine dinoflagellates such as *Protoperidinium conicum* and the diatom *Biddulphia smithii* were able to tolerate the drop of salinity to 3.2 and 15.3 PSU, respectively. The freshwater chlorophytes *Scenedesmus quadricauda, Sphaerocystis schroeteri* and *Pediastrum simplex* extend their tolerance to 38 PSU.

Monthly variations and species succession

The phytoplankton density varied widely during the study period between 1640 units l^{-1} (station 3, July) and 3 x 10^6 units l^{-1} (staton 4, March) with an annual average of 221 x 10^3 units l^{-1}. As in most estuarine regions, the succession through different months was obvious because of salinity and temperature changes and it demonstrated different patterns at different stations with different timing of peaks (Fig. 5).

Table 6: Dominant Phytoplankton species (>1% of total count), salinity range and salinity at maximum existence.

Table 6. Dominant phytoplankton species (>1% of total count), salinity range and salinity at maximum existance.

Species Sations	1	2	3	4	5	6	7	S‰ range	S‰ at maximum
Scenedesmus quadricauda	11.6	5.7	4.3	4.5	5.2	9.8	4.7	2.8-37.7	2.8
Scenedesmus dimorphus		1.5						2.8-17.8	3.2
Scenedesmus arcuatus		1.4						2.8-37.7	2.8
Scenedesmus bijugatus			1.5					2.8-14.7	2.8
Scenedesmus obliquus					1.2			2.8-22.5	2.8
Selenastrum gracile	6.9	2.6		1.9	3.1	12.1	1.4	2.8-38.0	24.9
Tetraedron minimum	14.9							2.8-37.6	5.2
Actinastrum hantzschii	1.3	27.0	1.3	3.5	3.3	15.6	9.6	2.8-37.7	2.8
Crucigenia rectangularis	2.2	2.1		1.7		2.6	2.0	2.8-38.0	2.8
Crucigenia quadrata			1.5			1.4		2.8-37.7	2.8
Crucigenia tetrapedia		2.2	1.6					2.8-35.7	3.2
Schroederia sp.	1.0	1.0		5.8	18.8	6.6	13.0	2.8-39.0	27.1
Ankistrodesmus setigera					16.4	1.3	13.8	2.8-39.0	17.9
Ankistrodesmus fusiformis		1.3					5.7	2.8-9.7	7.8
Ankistrodesmus spiralis		1.3						2.8-35.7	2.8
Carteria globosa		2.4		1.1				2.8-37.6	2.8
Pediastrum simplex			1.3		2.7	1.3		2.8-38.0	2.8
Pediastrum duplex			1.3		1.8			2.8-37.7	3.3
Micractinium pusillum					1.3			2.8-5.2	2.8
Sphaerocystis schroeteri						4.3		2.8-37.2	2.8
Cyclotella meneghiniana	3.9	7.8	3.5	2.3	4.8	4.9	4.1	2.8-37.8	13.4
Cyclotella comta		5.1					3.9	13.0-32.7	13
Nitzschia palea	15.7	6.2	16.7	5.8	2.6	8.1	1.7	2.8-39.0	2.8
Nitzschia microcephala	2.7	1.2						2.8-39.0	2.8
Biddulphia alternans			7.5					14.7-38.6	15.3
Biddulphia smithii	1.7							15.3-36.9	35.2
Navicula cryptocephala						1.1		2.8-39.0	24.9
Navicula borealis						1.2		2.8-38.0	2.8
Navicula gracilis	1.1	1.6	1.0					2.8-37.7	22.4
Cymbella lanceolata	1.2				1.1			2.8-39.0	12.9
Melosira granulata	2.1	2.1					5.5	2.8-39.0	2.8
Gomphonema olivaceum						3.0		2.8-37.8	12.5
Asterionella japonica			3.5					14.7-35.7	35.7
Licmophora gracilis			1.1					22.5-39.0	37.2
Skeletonema costatum	2.3	1.9		58.0	2.8	2.2	19.6	8.9-34.4	17.8
Synedra nitzschioides		1.6						2.8-39.0	37.2
Synedra ulna		1.1			1.7	1.6	1.2	2.8-37.7	2.8
Gymnodinium sp.	3.2	1.9	6.1		1.0	1.5		2.8-39.0	2.8
Exuviaella compressa	2.4	1.2	3.0		3.0			2.8-38.6	13.3
Protoperidinium conicum			7.1					3.2-35.6	13.3
Protoperidinium triestinum			13.1					13.3-39	13.3
Dactylococcopsis acicularis	1.5			1.1		1.4		3.2-37.2	9.2
Total percent	**75.7**	**80.2**	**75.4**	**85.7**	**70.8**	**80**	**86.2**		

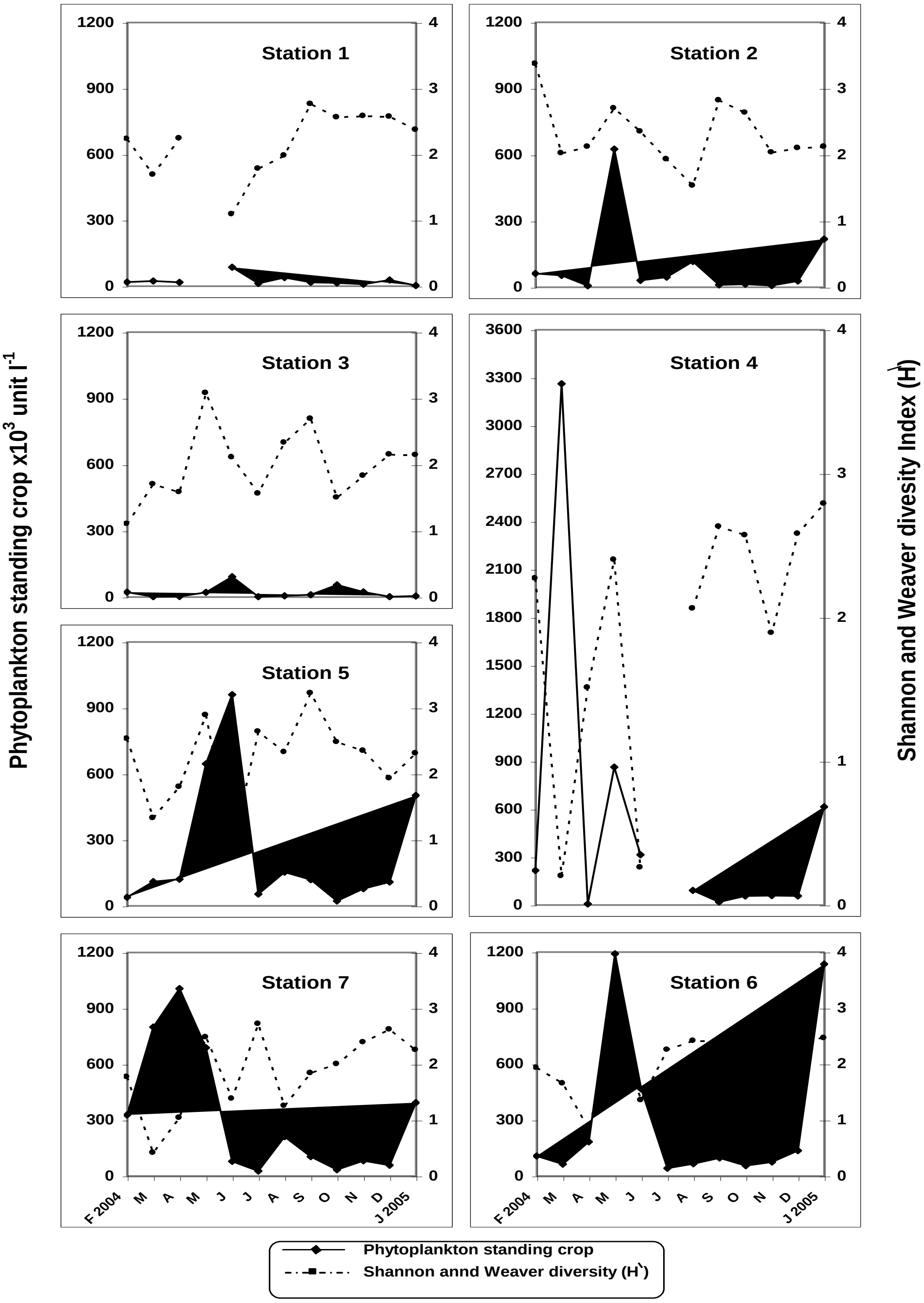

Figure 5: Monthly variation of phytoplankton standing crop and Shannon and weaver Index (H) in the sampled stations.

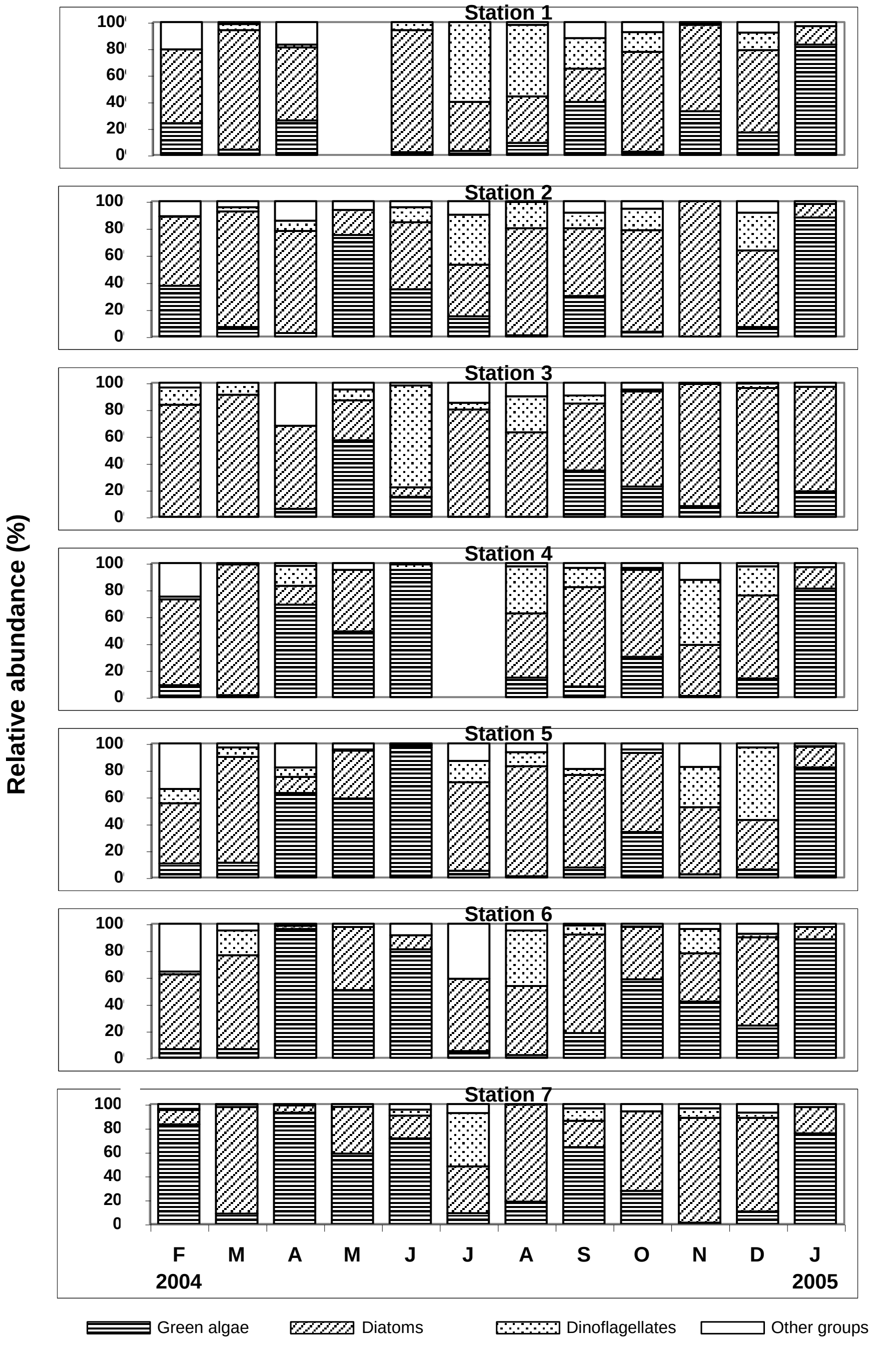

Figure 6: Monthly relative abundance (%) of different phytoplankton group at the sampled stations in Rosetta Estuary.

Fig. 6. Monthly relative abundance (%) of different phytoplankton groups at the sampled stations in Rosetta Estuary.

One peak was observed at station 1 in January (263 x 10^3 units l^{-1}), resulting from the increased numbers of small coccoid green algae, as *Tetraedron minimum* and *Scenedesmus quadricauda* at salinity up to 5.2 PSU. Two unequal peaks (626 x 10^3 and 218 x 10^3 units l^{-1}) were recorded at station 2 in May and January, respectively.

Both peaks were due to the flourishing of *Actinastrum hantzschii* at salinity between 3.2-5.3 PSU. Two other unequal peaks were observed at station 3, the first in June due to *Prorocentrum triestinum* (92×10^3 cells l^{-1}) at salinity 13.3 PSU and the second in October due to *Nitzschia palea* (55×10^3 cells l^{-1}) at salinity 38.0 PSU. An abnormal peak occurred in March at station 4, with absolute dominance of *Skeletonema costatum* (3×10^6 cells l^{-1}) at salinity 17.8 PSU. Other increases were observed in May and January resulting from the genera *Actinastrum*, *Scenedesmus*, *Selenastrum* and *Nitzschia* with prevailing freshwater at salinity less than 2.8 PSU. Station 5 registered two blooms; the first extended from May to June (646×10^3 – 961×10^3 units l^{-1}) resulting from the increased numbers of *Ankistrodesmus*, *Actinastrum* and *Schroederia* at salinity 3.3 PSU and the second bloom in January ($502 x 10^3$ units l^{-1}) ,due to *Actinastrum* at salinity less than 2.8 PSU. Other increases were recorded in November-December, due to the presence of the dinoflagellate *Exuviella compressa* (22×10^3, 57×10^3 cells l^{-1}, respectively) at salinity 13.3 – 22.5 PSU. Two equal peaks were recorded at station 6; in May (1191×10^3 units l^{-1}) and in January (1135×10^3 units l^{-1}), due to *Aclinastrum, Scenedesmus* and *Nitzschia* (S‰ < 2.8 PSU). Other increases were observed in June, due to *Selenastrum gracile* (125×10^3 cells l^{-1}) and in March, due to *Protoperidinium conicum* (9×10^3 cells l^{-1}). One distinguished peak was observed at stations 7 in April (1006×10^3 units l^{-1}), resulting from *Ankistrodesmus setigerus* which occurred at salinity 17.9 PSU and other increases were observed in February due to *Ankistrodemus fusiformis* (215×10^3 cells l^{-1}), in March due to *Skeletonema costatum* (685×10^3 cells l^{-1}) and in August due to *Cyclotella comta* (146×10^3 cells l^{-1}).

Monthly variations in the relative abundance of the main phytoplankton groups showed that diatoms dominated community composition at the outer stations during most of the year (Fig. 6). Nevertheless, diatoms declined in May and January when they were replaced by green algae that reached a relative density higher than 75% (station 2) or by dinoflagellates that reached 76 and 60% in June (station 3) and July (station. 1), respectively. At the inner stations, Chlorophyta were the most dominant division, mostly with the flow of fresh Nile water with low salinity values during April (90.5%), May (53.5%), June (91.6%) and January (83.6%).

Indices of diversity, evenness and species richness were employed as parameters to define the structure of the phytoplankton community in the estuary. Generally, the Shannon-Wiener diversity index increased towards the outer stations reaching a maximum average value of 2.31 at station 2. It was found to be between 0.20 (station 4, March) and 2.89 (station 5, May) at the inner stations and between 1.1 (station 3, February) and 3.37 (station 2, February) at the outer stations (Fig. 5). The biodiversity and evenness were also affected by Rosetta Nile flushes and decreased with high influence of the freshwater current. Evenness indices were calculated to be a minimum of 0.01 (station 4, March) and a maximum of 0.41 (station 5, February) at the inner stations and between 0.07 (station 1, April) and 0.52 (station. 1, February) at the outer stations (Fig.7). The low diversity index indicates a weak community structure and low diversity and eveness point to the dominance of some taxa, as in March, due to the excessive bloom of *Skeletonema costatum* (3×10^6 cells l^{-1}, station

4 in March). A high diversity index during February and May indicates a strong community structure. The mean values of these indices showed that station 2 which lie at the mouth of the estuary sustained usually high values of both indices.

DISCUSSION

The distribution of phytoplankton in estuaries and coastal waters is characterized by high spatial and temporal variability. Phytoplankton species of 7 classes were distinguished. The two major phytoplankton groups, Chlorophyta and Bacillariophyta, are strongly separated temporally by season, and spatially along the estuary according to flow and salinity. Bacillariophyta exhibited the widest range of maximum potential growth rates and occurred under a wide range of discharges. Chlorophyta, the dominant division at the inner stations were be able to tolerate fluctuations in salinity, while Dinophyta, were dominated by relatively few brackish water species, and occurred at low discharges.

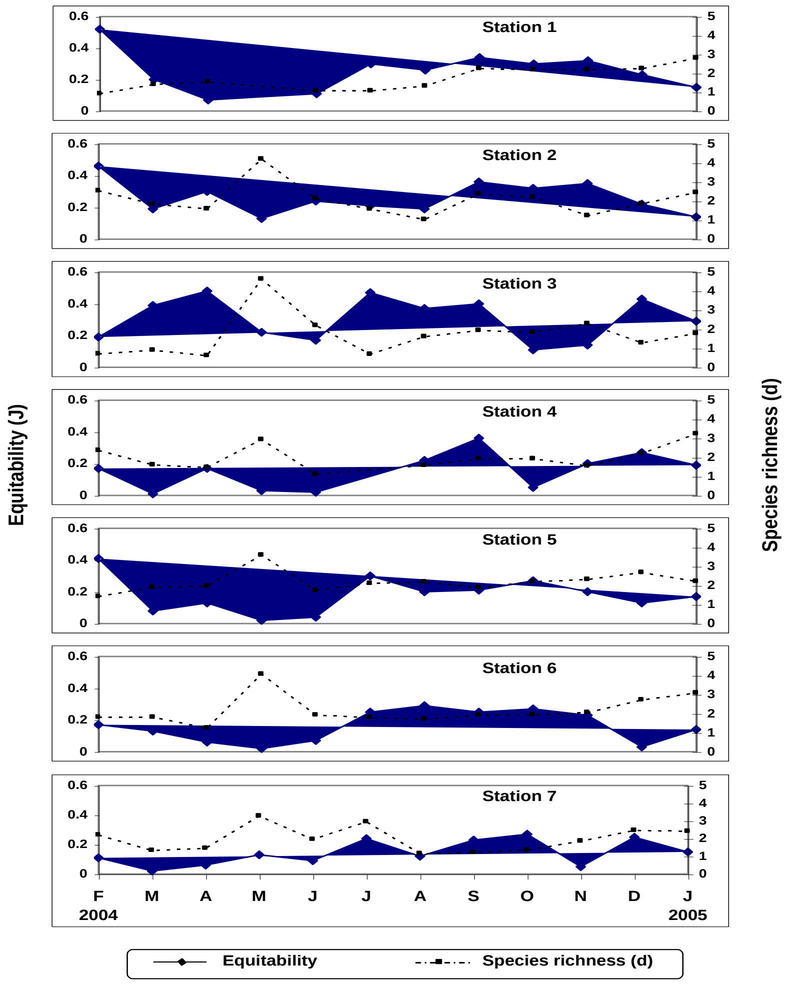

Fig. 7. Monthly variations of equitability (J) and species richness in the sampled stations.

Figure 7: Monthly Variations of equitability (J) and species nchness in the sampled stations.

As in many other estuaries, nutrients appear to be less important than flow and salinity in regulating phytoplankton succession and abundance [23,24]. 152 taxa were identified from phytoplankton samples of Rosetta estuary with density ranging from 1640 units l^{-1} to 3263 x 10^3 units l^{-1} and generally decreased toward the mouth of the estuary.

In spring, as well as in summer, diatoms dominated the phytoplankton community, while green algae were relatively more important in late spring (May) and autumn. In spring, a relative increase in green algae was observed although diatoms remained dominant.

Due to the great salinity fluctuations in Rosetta estuary, the size spectra of phytoplankton species were larger than those in the River Nile or the Mediterranean Sea [25, 26, 9]. In the River Nile, the phytoplankton community comprised 64 species, including 32 species of Chlorophyceae, 17 of Bacillariophyceae, 10 of Cyanophyceae, beside 4 species of Euglenophyceae and one of Dinophyceae . *Melosira granulata* var. *angustissima*, *Cyclotella meneghiniana* ,*Pediastrum* spp., *Scenedesmus* spp, and *Eudorina elegans* formed the main bulk [9, 25]. On the other hand, the algal community of the Western Harbour in the Mediterranean Sea, was represented by 72 species of which *Cyclotella meneghiniana*, *Nitzschia delicatissima*, *Prorocentrum cordatum* and *Euglena granulate* were the dominant [26].

Magnitudes of phytoplankton abundance in the present study differed from previous studies. This may be due to the increase in environmental pollution caused by industrial and urban development in the study region. Zaghloul [8] showed that phytoplankton population in Rosetta Estuary was more abundant (average 1.3 x 10^6 units l^{-1}) during 1972-1973, decreased to average 0.5 x 10^6 units 1^{-1} during 1986-1987 [9], decreased to average 221 x 10^3 units l^{-1} during 2004-2005 (the present study). In the first two periods diatoms were more abundant followed by cyanophytes. The number of species also differed between the present study and the previous works . Zaghloul [9] recorded 57 species with maximum persistence to *Melosira granulata*, *Pediastrum simplex* and *Microcystis aeruginosa*. However, Asterionella *japonica* and *Thalassionema nitzschioides* were dominant diatom species during 1972-1973 [8]. These species were of minor constituents in the present study, in spite of the similar sampling periods and surface water temperatures were almost identical to that of previous studies. Thus, the floral differences between the present results and previous studies were large year to year, or even showed small variations in dominant species in Rosetta estuary and the estuary is subjected to huge inputs of terrigenous and anthropogenic nutrient from river discharge, sewage and agricultural runoff. The present study occupied the end portion of Rosetta Branch strongly affected with saline Mediterranean water and both marine and freshwater phytoplankton are unable to grow quickly enough to build up a large population [27].

The most pronounced salinity effect was observed for Cyanophyceae which had relatively high proportion in February and May at the inner stations with water salinity below 2.8 PSU.

The extent of similarity index ranged from 60 to 80%, with the highest similarity between stations 1 and 2. Two different assemblages were recognized; the first was distributed at stations 1, 2 and 3, that was most affected by seawater and the second at stations 4-7. The most dominant species for the first assemblage was *Prorocentrum triestinum,* which is an estuarine species, best adapted for life in either fresh or salt water and is marine in origin [28]. *Skeletonema costatum* was the most common species in the estuary formed more than 24% of the average total counts; it reached 3 x 10^6 cells l^{-1} in March (station 4) at salinity of 17.8 PSU. The species is a neritic diatom with optimum salinity of 19.5 PSU and declines as salinity deviates from this optimum [29]. It is also a euryhaline and eurythermal species which can grow quickly under eutrophic conditions [30].

The diversity index is a function of the number of species present and the evenness with which the individuals are distributed among these species [31,32]. The diversity of any aquatic community is usually affected by any disturbance in the surrounding ecological conditions, which is more pronounced in the estuarine areas. In Rosetta Estuary, salinity variation was the most characteristic feature that has crucial role in the changes of diversity of phytoplankton community. Species diversity, richness and evenness were mostly high at the outer stations 1 and 2. This may be resulting from aggregation of both fresh and marine species, which agree with the observation of Margalef [5] and Kingston *et al.* [33], who reported that diversity would be higher when two different communities mix together.

It appeared that variations in number of species or richness reflected on the diversity index, that had wide monthly variations at each station and also between stations every month. However, diversity index, similar to richness, increased as water salinity decreased, reflecting the effective contribution of the freshwater species. This is clearly shown from the negative relationship between salinity and diversity ($r = -0.23$, $p < 0.05$, $n = 75$) and richness ($r = -0.43$, $p < 0.001$, $n = 75$). Blinn [34] supported this conclusion in saline lakes. On the other hand, lower salinity enhanced greater phytoplankton abundance ($r = -0.33$, $p \leq 0.05$, $n = 75$), as reported by Herbst and Blinn [35]. This was pronouncedly appeared when compared the inner stations which were more productive than the outer ones.

Several of the dominant species, either marine or freshwater, demonstrated different tolerance ranges to salinity variations (Table 6). The freshwater chlorophytes, as well as the marine dinophytes, can withstand the widest salinity variations (2.8 – 39 PSU). The freshwater chlorophytes *Actinastrum hantzschii, Sphaerocystis schroeter*i and *Scenedesmus quadricauda* extend their tolerance to 37 PSU.On the other hand, marine or brackish forms could not tolerate low salinity and were restricted to relatively high salinity (13-39 PSU) like *Biddulphia alternans*, *Biddulphia smithii* and *Prorocentrum triestinum.*

The dominant pattern of water salinity was the gradual increase towards the mouth and the flow usually take the eastern direction (station 1). Intermittently seawater entering to the inner stations, increased the salinity sometimes up to 24.2 PSU at station 7, which usually sustained lower values of diversity and evenness indices.

The phytoplankton community in Rosetta estuary was characterized by the dominance of large numbers of species, fluctuating between 10 species (station 4) and 21species (station 2) that form more than 1% of total count.

CONCLUSION

Freshwater discharge affects the residence time available for different phytoplankton taxa to grow. It also influences succession between marine, estuarine and freshwater phytoplankton taxa according to the extent hindering the intrusion of marine water into the estuary.

The results indicated freshwater and estuarine populations forming a diverse assemblage of 152 taxa, with diatoms and chlorophytes the dominant flora. Phytoplankton was predominantly freshwater taxa (> 70%) with a diverse diatom assemblage representing > 44% of the estuarine flora. The two major phytoplankton groups, Bacillariophyta and Chlorophyta are strongly separated temporally and spatially along the estuary according to flow and salinity.

The main manifestations of the phytoplankton community structure included more irregular water blooms, decreased in total cell counts, increased in the number of species and also increased in the number of species, which contributed significantly to the phytoplankton abundance.

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