EJAR

The biological pump of carbon dioxide in El-Mex bay, Alexandria, Egypt

Thanaa H. Mahmoud*, Mamdouh S. Masoud, Nayrah A. Shaltout* and Nabila R. Hussien***

**National Institute of Oceanography and Fisheries, Alexandria*
***Chemistry Department, Faculty of Science, Alexandria University*
E-mail, Nayrahshaltout@yahoo.com

Received 8th June 2009, Accepted 9th August 2009

Abstract

El-Mex Bay is a shallow sheltered estuary west of Alexandria extends between longitude 29° 47' to 29° 50'E and latitude 31° 7' to 31° 9'. It receives a heavy load of waste water from El-Umum Drain, Sodium Bicarbonate and Chloro Alkali Plant factories. Samples were collected during August (summer) 2004 from surface water of stations I, VIII, IX and XII which represents water types of different salinity L, M_1, M_2 and D respectively. Environmental variables such as, temperature, salinity, dissolved oxygen, carbon dioxide and total alkalinity concentrations were measured. Gross primary production (GPP), community respiration (CR) and net community production of phytoplankton (NCP) for El-Mex Bay were calculated. It is found that at water type "L" (station I) GPP values is the lowest (45.37 mg C $m^{-3}h^{-1}$) and the highest at water type M_1 (station IX). Community respiration (CR) content varied between -282.3 mg C $m^{-3}h^{-1}$ to 167.38 mg C $m^{-3}h^{-1}$ at water types L and M_2. Water type "L" could be considered as heterotrophic system while water types M_1, M_2 and D are classified as autotrophic system. Net community production (NCP) values varied between 147.89 mg C $m^{-3}h^{-1}$ at water type M_2 and 327.71 mg C $m^{3}h^{-1}$ at water type M_1.

1. Introduction

El-Mex Bay is located between longitudes 29° 47.1′ to 29° 50.4′ E and latitudes 31° 7.5′ to 31° 9′ N, representing a shallow sheltered estuary west of Alexandria. It is elliptical in shape, extends for about 15 km between El-Agami headland to the west and the Western Harbour to the east and from the coast to a depth of about 30 m with a mean depth of 10m (Fahmy *et al*., 1997, Samir and Badr El-Din, 2001, Mahmoud *et al*., 2005, Shriadah and Emara 1996). A huge amount (about 6.75×10^6 m^3 d^{-1}) of agricultural, industrial and domestic waste water discharged into the bay from El-Umum Drain without any effective treatment. There are another pipeline discharges directly to the bay such as Chloro Alkali Plant Drain (CAP), Misr Chemicals Industries Company combined with the effluent from Sodium Bicarbonate Factory. The Western Harbor mouth which lies to the east of El Mex Bay also discharge waste water from the harbor.

The role of coastal ecosystems in carbon and nutrient fluxes can be conveniently summarized by their trophic balance, referring to the difference between the total amount of organic carbon produced by photosynthesis, as represented by the gross primary production (GPP) of the ecosystem, and its oxidative consumption by autotrophic and heterotrophic organisms through community respiration (CR) (Bender *et al.*, 1987; Heip *et al.*, 1995; Serret *et al.*, 2001). The balance between gross primary production (GPP) and community respiration (CR) is the net community production (NCP) = (GPP – CR). An ecosystem is autotrophic when production of organic matter by primary producers exceeds the consumption of this matter by the overall community. This could be expressed as GPP>|CR| (if CR is expressed in negative units), thereby such systems are potentially net sinks for atmospheric carbon dioxide (CO_2) (Gazeau *et al.*, 2005a). In contrast, heterotrophic ecosystems, organic matter consumption exceeds primary production, rely on allochtonous inputs of organic matter, where GPP<|CR|, leading generally to high CO_2 partial pressure (pCO_2) and low dissolved oxygen (O_2) concentration in the water column (Duarte and Prairie, 2005; Frankignoulle *et al*., 1998).

Primary production is controlled by complex combinations of physical (temperature and light availability), biological (growth rate) and chemical factors (nutrient availability) (Gattuso *et al*., 1998; Chester, 2001). In addition, NCP in costal areas depends on several forcings such as the ratio between nutrients and carbon inputs (from rivers, estuaries and lateral inputs), and the physical features (such as residence time of water masses, circulation, light availability within the water column, seasonal stratification of the water column). The determination of NCP is of interest for the understanding of the carbon dioxide cycle within a given area.

There is no simple relationship between NCP and pCO_2. Indeed the surface pCO_2 is driven by other biogeochemical processes ($CaCO_3$ production/ dissolution), DIC lateral inputs (Cai *et al.*, 1999; Gazeau *et al.*, 2005b), thermodynamical effects (in particular temperature change), physical processes such as wind speed, advection of water masses.

Historically, GPP, CR and NCP were first investigated on regional scales using the oxygen light-dark (O_2-LD) method (Riley 1939). Steemann (1952) introduced the ^{14}C incorporation method which, at the time, was much more precise than the O_2-LD method and allowed shorter incubation times. This method has been extensively used and has become the most common way for measuring primary production, although the sensitivity of the O_2-LD technique has since been considerably improved (Howarth and Michaels, 2000). Moreover, several problems with the use of the ^{14}C method have been identified and it is advisable to be careful when interpreting data based on it (Peterson, 1980).

Numerous studies have focused on the comparison between GPP estimates based on the O_2-LD technique (O_2-GPP) and primary production measured by the ^{14}C method (^{14}C-GPP). Several studies suggested that the ^{14}C method with incubations lasting from 12 to 24 h provides a rate closer to NCP (Eppley, 1980) while others found a reasonable correspondence between the two methods in oligotrophic and eutrophic environments (Bender *et al.*, 1987, Williams *et al.*, 1983; Longdon *et al.*, 1995).

Gazeau *et al.* (2007) compared rates of primary production measured using three different incubation methods: (1) the oxygen light-dark method (O_2-LD), (2) ^{14}C incorporation and (3) ^{18}O labeling by in two estuaries (Randers Fjord, Denmark, and the Scheldt estuary, Belgium/The Netherlands). They found that, the estimates based on the ^{14}C incorporation technique were not significantly different from those obtained using the O_2-LD technique while the ^{18}O approach provided rates is significantly lower. They attributed the underestimation of gross primary production by the ^{18}O method to an intracellular recycling of labeled oxygen which increased in magnitude with decreasing external oxygen conditions. These results suggest that the ^{18}O method must be used with extreme care in nutrient-rich and low oxygen systems.

2. Material and Methods

Samples for photosynthesis measurements by incubation of light and dark bottles were collected in 10 liter polyethylene bottles from a depth of 0.5m at stations I, VIII, IX, X and XII during August 2004, (Figure 1). These stations represent different water types registered at the Bay (Mahmoud *et al.*, 2005). Station I represents water type L, stations VIII and IX represent water type M1, station X represents water type M2 and Station XII represents water type D.

Estimation of the magnitude of phytoplankton counts was carried out by using the sedimentation method (A.P.H.A., 1985), the different species were identified, counted and estimated as unit. l^{-1}. Each sample was examined in triplicate to improve accuracy. Photosynthetic rates were estimated according to Strikland and Parsons (1972) and Carrillo (2002) by variation in O_2 during light incubation experiments (photosynthesis) and dark community respiration (DCR). For photosynthesis estimation sea water samples were filtered through clean nylon netting with mesh size 30 µm net to remove the larger zooplankton. BOD (300 ml) Pyrex bottles were used for incubation experiment, two clear bottles (light bottle, LB) and initial bottle (IB) and one opaque bottle (dark bottle, DB) are needed to be filled in triplicate for each sample to improve the overall precession. The LB and DB were incubated in situ at the desired location at the sea for about 3 hours. Sea water samples in IB were immediately analyzed while LB and DB were analyzed after incubation period of 3 hours. Dissolved oxygen samples (mg O_2 l^{-1}) were analyzed according to modified Winkler method (Grasshaff; 1976), pH values were measured immediately after collection using a portable pH meter HACH, (EC10). Total alkalinity content was detected according to Haraldsson *et al.* (1997) and Dickson (2003). Water salinity values were determined from the electrical conductivity ratio using a Bekman induction salinometer model RS-7C. Nutrient salts in µmol l^{-1} (ammonia (NH_3), nitrite (NO_2), nitrate (NO_3), phosphates (PO_4-P) and silicates (Si_2O_3) were determined following Grasshaff (1976) using a Shimadzu Double Beam Spectrophotometer model UV-150-02. Surface water temperature was measured immediately in the field using standard thermometer accurate to 0.1 °C. Changes in carbon dioxide pCO_2 and buffer factor in each bottle were calculated from measurements of alkalinity and pH using CO_2-SYS. Corresponding CO_2 flux were calculated according to the equation:

$$FCO_2 = k\ \alpha\ \Delta pCO_2$$

Where; ΔpCO_2 (ppm) is the pCO_2 gradient between water and atmosphere respectively, α is CO_2 solubility coefficient (in mol m^{-3} μatm^{-1}) calculated according to Weiss (1974), and k; is the gas transfer velocity (m d^{-1}).

Gross primary photosynthesis (GPP), community respiration (CR) and net community production (NCP) are calculated from the following equations:

$$GPP\ (mg\ C\ m^{-3}\ h^{-1}) = 605\times f \times [V_{(LB)}-V_{(DB)}] / (N\times PQ)$$

$$NCP\ (mg\ C\ m^{-3}\ h^{-1}) = 605\times f \times[V_{(LB)}-V_{(IB)}] / (N\times PQ)$$

$$CR\ (mg\ C\ m^{-3}\ h^{-1}) = 605\times f \times [V_{(IB)}-V_{(DB)}] \times RQ/ N$$

where: $V_{(LB)}$, $V_{(DB)}$ and $V_{(IB)}$: are the thiosulphate titration volume obtained within the three types of bottles. N: time of incubation in hours, and PQ and RQ: they are dimensionless numbers indicating the relative amount of oxygen and carbon involved in the process of photosynthesis and respiration, since;

PQ = photosynthesis Quotient = $+\Delta O_2 / -\Delta CO_2 \cong 1.2$
RQ = Respiratory Quotient = $+\Delta CO_2 / -\Delta O_2 \cong 1.0$

3. Results and Discussion

Based on the distribution of salinity in the Bay surface water could be divided to three water types, diluted sea water "D" with salinity ranged from 30 to 35. Mixed sea water "M" with salinity ranged between 10 and 30, this water type could be classified into 2 subtypes, "M_1" which mainly affected by waste water discharge from El-Umum Drain and M_2 which is affected by water of Western Harbour opening. The last water type is Water type "L" which is affected directly by El-Umum Drain water and showed salinity < 10. Water quality of different water types is illustrated in Table (1). From the table it could be noticed that water type "L" had lower pH (7.75), salinity (4.27), dissolved oxygen (2.6 mg O_2 l^{-1}) and higher concentrations of ammonia 90.21 µmole l^{-1}, nitrite 12.45 µmole l^{-1}, nitrate 42.92 µmole l^{-1}, phosphate 11.57 µmole l^{-1}, silicate 126.28 µmole l^{-1} and total alkalinity6165.89 µeq Kg^{-1} than water type "D" pH (8.07), salinity (34.43), dissolved oxygen (12.30 mg O_2 l^{-1}) and lower concentrations of (ammonia 2.10µmole l^{-1} , nitrite 0.47 µmole l^{-1}, nitrate 2.57 µmole l^{-1} phosphate 0.55 µmole l^{-1}, silicate 2.47 µmolel^{-1} and total alkalinity 2900.63 µeq Kg^{-1}. Water type M1 and M2 showed intermediate levels of nutrient salts, dissolved oxygen and alkalinity.

Table 2 illustrates the changes in carbon dioxide, dissolved oxygen; nutrient salts and total alkalinity content in different sea water samples for samples before and after incubation experiment for light, dark and initial bottles at different water types. Salinity values and phytoplankton quantity for each sample are also tabulated. It is easily to account for CO_2, DO_2, and nutrient salts involved in photosynthesis and respiration processes. The variation in concentration of the previously mentioned variables either decreased or increased after incubation period could be calculated by subtract their initial concentration in the bottle (IB) from their concentrations in the light (LB) and dark bottles (DB). The data presented in table 2 showed that, for water type L considering photosynthesis process, there is a sharp decrease in nitrate content (9.89 µmol l^{-1}) accounts for nitrate assimilation during this process and this is coincided with an increase in total alkalinity value 44.50 µeq kg^{-1} this is in consistence with the found of Brewer and Goldoman (1976) where nitrate uptake raises total alkalinity. Nevertheless, the increase in nitrate is not in stoichiometry with the increase in total alkalinity. The same case was found in the polluted Scheldt basin, Abril and Frankignoulle (2001) and they attributed this variation to the higher turbidity and oxygenation conditions of anthropogenic input by aerobic and anaerobic processes. The rapid deplation of nitrate is accompanied with reduction in manganese, iron and sulphates, which contributing to the alkalinity increase. These facts are also verified by the increase in oxygen content in light bottle resulted from photosynthesis 0.43 mg O_2 l^{-1} and the decrease of CO_2 (-57.00 µmol kg^{-1}). The unexpected decrease of CO_2 content after incubation in dark bottle (respiration process) (-62.4 µmol kg^{-1}) indicates the presence of anaerobic, heterotrophic organic respiration and aerobic oxidation respiration (nitrifiers, sulfur oxidizers and methanotraphs). This phenomenon is confirmed by a decrease in total alkalinity (-160.3µeq kg^{-1}). The nitrifies effect is verified by a decrease in ammonia content (-41.90 – 36.23 µmol l^{-1}) and an increase in nitrite (11.82, 11.98 µmol l^{-1}) during both photosynthesis and respiration processes.

It is observed from Table 2 that total alkalinity, nitrite, nitrate and phosphates concentrations decrease at both respiration and photosynthetic processes in water type M1 (170.45 and -685.2 µeq kg^{-1}), (-3.52 – 3.37 µmol l^{-1}), (-3.11, -4.43 µmol l^{-1}) and (-2.03, -2.28 µmol l^{-1}) respectively. In this water type carbon dioxide and Dissolved O_2 (DO) content are a mirror image of each other. During photosynthesis oxygen content increased (2.65 mg O_2l^{-1}) and carbon dioxide decreased (-4.20 µmol kg^{-1}). In respiration process it is found that oxygen content decreases -1.12 mg O_2l^{-1} and carbon dioxide increases 0.15 µmol kg^{-1}. Ammonia values increase 3.04 µmol l^{-1} during respiration due to excretion of zooplankton and bacteria as well as the decomposition of organic matter in the dark bottles.

In water type M_2 which is affected by industrial wastes, it is found that total alkalinity at both light and dark bottles increases (121.80, 33.6 µeq kg^{-1}) greatly reflecting the effect of industrial wastes on the photosynthesis and respiration processes not only the biological effects. On the contrary, nitrate (-8.87, -9.21 µmol l^{-1}) nitrite (-4.85, -1.20 µmol l^{-1}) and phosphates values (-2.51, -2.86 µmol l^{-1}) decrease at those two processes. Oxygen and carbon dioxide in this water type are a mirror image of each others at light and dark bottles (1.62 and -0.97 µmoll^{-1}) and (-0.3 and 2.70 µmol l^{-1}).

Water type "D" which is a diluted sea water nutrient salts content decrease during both photosynthesis and respiration processes, ammonia (-1.68 and -0.85 µmol l^{-1}), nitrate (-3.43 and -3.51 µmol l^{-1}) and phosphates (-0.31 and -0.22µmol l^{-1}) carbon dioxide and oxygen concentrations are reversely correlated with each other during photosynthesis and respiration processes (-0.40 and 0.70µmol kg^{-1}) and (2.46 and -0.81mg O_2l^{-1}).

In water types M_1, M_2 decreases of nitrite, nitrate and phosphates after incubation time may be due to their uptake by phytoplankton during photosynethic processes, (Fan *et al.*, 2003 and Maestrini *et al.*, 1999).

Regional variations of Gross primary production (GPP), community respiration (CR), net community production (NCP) and phytoplankton community count, at El-Mex Bay surface water in summer 2004, at different water types are calculated using the previously mentioned equations and are represented in (Table 3) and (Figure 2). It is observed that water type L showed the lowest GPP values (45.37 mg C m^{-3} h^{-1}), in spite its nutrient salts content are very high (NH_4^+= 274.75 μmol l^{-1}, NO_2^- =12.62 μmol l^{-1}, NO_3^- =15.47 μmol l^{-1} and PO_4 = 21.13μmol l^{-1}). This observation may be attributed to low phytoplankton content (0.25×10^{6} cell l^{-1}), high turbidity and high organic matter content at this water type. Increasing turbidity will decrease light availability, consequently decrease primary production. Parsons *et al.* (1977) found that, the maximum primary production is often found at some distances from the discharged water although nutrients levels may be lower there, that is due to light availability. The highest value of GPP 430.22 mg C m^{-3} h^{-1} is estimated for water type M_1 is coincided with highest phytoplankton content (3.57×10^{6} unit l^{-1}) (Figure 2).

Community respiration (CR) was varied largely from -282.3 mg C m^{-3} h^{-1} at water type L to 167.38 mg C m^{-3} h^{-1} at water type M_1 (Figure 2).

Net community production varied between (147.89 mg C m^{-3} h^{-1}) at water type M_2 and (327.71 mg C m^{-3} h^{-1}) at water type L (Figure 2).

It is noticed that water type L showed GPP < $|$CR$|$, since 45.37 < $|$-282.33$|$ (Table 3), which may indicate that organic matter consumption exceeds primary production, and this could be attributed to the allochthonous organic matter from El-Umum Drain. According to the statements of Frankignoulle *et al.* (1998) and Duarte & Prairie (2005), water type L could be classified as net heterotrophic system with a very high carbon dioxide partial pressure there in. The calculated pCO_2 at water type L, was (3607.92 μatm) and high CO_2 flux to the atmosphere (240.84 mmol m^{-2} d^{-1}) as shown in table 3.

For the other water types M1, M2 and D it is noticed that GPP > $|$ CR $|$ which may indicate their autotrophic characters since 389.89 > $|$139.15$|$, 268.89 < $|$121.00$|$, and 339.47 < $|$100.83$|$ for water type M1, M2 and D respectively. Therefore, they produce organic matter in excess and thereby they are potentially acted as a sink for atmospheric carbon dioxide at M_1. The recorded pCO_2 at these stations are (1015.34, 415.5 and 478.35μatm). The corresponding air sea flux at these water types are (47.72, 4.62 and 9.94mmol m^{-2} d^{-1}) respectively (Table 3).

Seasonal variation of Gross primary production (GPP), community respiration (CR), and net community production (NCP) at different water types of El-Mex Bay is calculated by integrating the primary production rates recorded in summer to the average phytoplankton community count at some stations (Figure 3) at different seasons. The daily GPP rate is estimated by multiplying hourly rates in each season by the numbers of hours of daylight at season in question (Randall and Day 1987). The hourly CR rate is multiplied by 24 hours to get daily community respiration. Daily net community production is estimated from daily GPP and CR according to (NCP) = (GPP – CR) (Gazeau *et al.*, 2005a). The calculated seasonal variations of GPP, CR, NCP at different water types and their annual average values were recorded in table (3). In winter, surface water showed lowest daily GPP (0.76 g C m^{-3} d^{-1}), CR (-1.5 g C m^{-3} d^{-1}) and NCP (2.29 g C m^{-3} d^{-1}). While in spring, surface water had the highest values for GPP, CR and NCP (66.29 g C m^{-3} d^{-1}, 4.78 g C m^{-3} d^{-1}, and 61.15 g C m^{-3} d^{-1}). During winter and autumn GPP < $|$CR$|$ since 0.78< $|$-1.53$|$ in winter and 0.94 < $|$-1.90$|$ in autumn, so surface water is a source of CO_2. While during spring and summer the situation is reversed since the recorded GPP > $|$CR$|$, 66.29 < $|$4.79$|$ in spring and 19.72 < $|$4.76$|$ in summer.

Water type "L" which is affected greatly by waste water had very low GPP annual average (4.75g C m^{-3} d^{-1}) and highest CR (63.33g C m^{-3} d^{-1}) and NCP (68.08gC m^{-3} d^{-1}). It is found that GPP<CR which indicates the allochthonous origin of organic matter and this water type is heterotrophic. Water type M_2 which is affected by the water discharge from Western Harbour opening had the highest GPP (44.0gC m^{-3} d^{-1}) and high value of CR (42.71 g C m^{-3} d^{-1}) while NCP exhibited is very low value (1.29 g C m^{-3} d^{-1}). Water type "D" which is a diluted sea water the annual average of GPP, CR and NCP are 14.66, 8.75, 5.91 g C m^{-3} d^{-1}. GPP>8.75 this indicates the autocthonous origin of organic matter. The system is a potentially sinks for atmospheric carbon dioxide.

Buffer factor which is a measure of capacity for sea waters to take up anthropogenic CO_2 from the atmosphere, hence, the lower the buffer factor, the higher the oceanic equilibrium concentration of anthropogenic CO_2 for a given atmospheric CO_2 perturbation (Sabine *et al.*, 2004; Sundquist & Plummer, 1981). β can also be used for identifying processes responsible for marine inorganic carbon dynamics, such as primary production, calcification or water mass mixing. Frankignoulle *et al.,* (1994) reported that, if organic matter production/respiration by organic metabolism has no effect on β, this value can decrease down to -7 under the influence of inorganic metabolism (e.g. uptake or release of bicarbonates and/or carbonates by calcifying organisms). Thus, the buffer factor has a wide range of values depending on the inorganic species involved in the CO_2 dynamics. Furthermore, the homogeneous buffer factor may provide substantial help in understanding inorganic carbon dynamics even in coastal waters where complex and intense biogeochemical processes co-occur (Frankignoulle *et al.*, 1996 a; Frankignoulle *et al.*, 1996 b).

The average buffer factor in water type D and M_2 are very close to the expected values for Revelle factor (ß=10). This indicates that total inorganic carbon variations measured in these water types are mainly driven by changes in the dissolved CO_2 level (eg. Air-sea CO_2 exchanges and/or organic matter production/degradation without any $CaCO_3$ precipitations). In case of water type M_1, it showed an average buffer factor β = 14. This is slightly higher value than water type M_2 and D because it is more affected by discharged water from El-Umum Drain leading to increase in productivity at this water type. Water type L showed extremely high β value (β = 23.8) reflecting a very small capacity to take up CO_2 from the atmosphere. This is attributed to very high DIC content 6007±291 μmol kg^{-1} and a very high pCO_2 recorded 4153 μatm accompanied with low pH 7.7 and very high total alkalinity TA = 5980±302.68 μeq kg^{-1} as a result of input of alkalinity rich water with average (TA= 6040.78±410 μeq kg^{-1} and DIC = 6047±389 μmol kg^{-1}) from El-Umum Drain.

Table 1: Water quality of surface water at El-Mex Bay at different water types during summer 2004.

Water Types	T	Salinity	pH	DO_2	NH_3-N	NO_2-N	NO_3-N	PO_4-P	Si_2O_3-Si	TA
	ºC			mg O_2 l^{-1}	μmol l^{-1}					μeq kg^{-1}
L	28.28	4.27	7.75	2.6	90.21	12.45	42.92	11.57	126.28	6165.89
M1	28.31	19.95	8.15	10.68	47.34	7.43	16.57	6.85	72.38	4786.98
M2	28	28.24	8.29	13.85	18.41	4.89	10.91	4.62	46.2	4316.43
D	27.5	34.43	8.07	12.3	2.1	0.47	2.57	0.55	2.74	2900.63

Table 2: changes of pH, DO_2, TA, DIC, $[CO_2]$, NH_4, NO_2, NO_3, PO_4, Si_2O_3.

Water Type		pH	DO_2	TA meq kg^{-1}	DIC mmol kg^{-1}	$[CO_2]$ mmol kg^{-1}	NH_3-N	NO_2-N	NO_3-N	PO_4-P	SiO_4-Si
							μmol l^{-1}				
L	L-I	0.23	0.43	44.5	-129.7	-57	-41.9	11.82	-9.89	-2.05	-75.76
	D-I	0.22	-2.27	-160.3	-317.4	-62.4	-36.23	11.98	-9.07	-2.2	-70.58
M1	L-I	0.15	2.65	-170.45	-377.95	-4.2	-32.93	-3.11	-3.52	-2.03	-1.58
	D-I	-0.06	-1.12	-68.5	-509.85	0.5	3.04	-4.43	-3.37	-2.28	0.03
M2	L-I	0	1.62	121.8	23.2	-0.3	-0.02	-4.85	-8.87	-2.51	-1.72
	D-I	-0.07	-0.97	233.6	267.7	2.7	9.05	-1.2	-9.21	-2.86	3.82
D	L-I	0	2.46	-5.7	-46.9	-0.4	-1.68	0.3	-3.43	-0.31	14.3
	D-I	-0.12	-0.81	30.4	132.1	0.7	-0.85	-0.54	-3.51	-0.22	2.28

Table 3: Phytoplankton community count, Gross primary production (GPP), community respiration (CR), net community production rates, carbon dioxide partial pressure, air sea carbon dioxide flux, and buffer factor at different stations in El-Mex Bay surface water, summer 2004.

Water types	Phyto×10^6 (unit l^{-1})	GPP (mg C m^{-3} h^{-1})	CR (mg C m^{-3} h^{-1})	NCP (mg C m^{-3} h^{-1})	pCO_2 (μatm)	fCO_2 (mmol C $m^{-2}d^{-1}$)	ß
L	0.25	45.37	-282.33	327.71	3607.92	240.84	23.85
M1	3.61	389.89	139.15	250.74	1015.34	47.72	13.90
M2	0.59	268.89	121.00	147.89	415.50	4.62	10.11
D	0.54	339.47	100.83	238.64	478.35	9.94	10.81

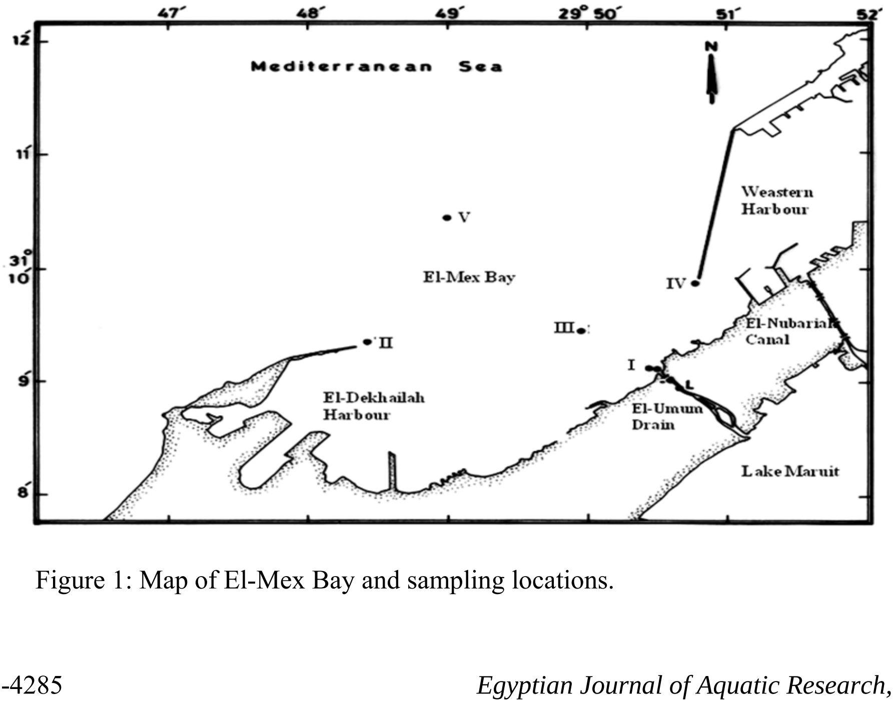

Figure 1: Map of El-Mex Bay and sampling locations.

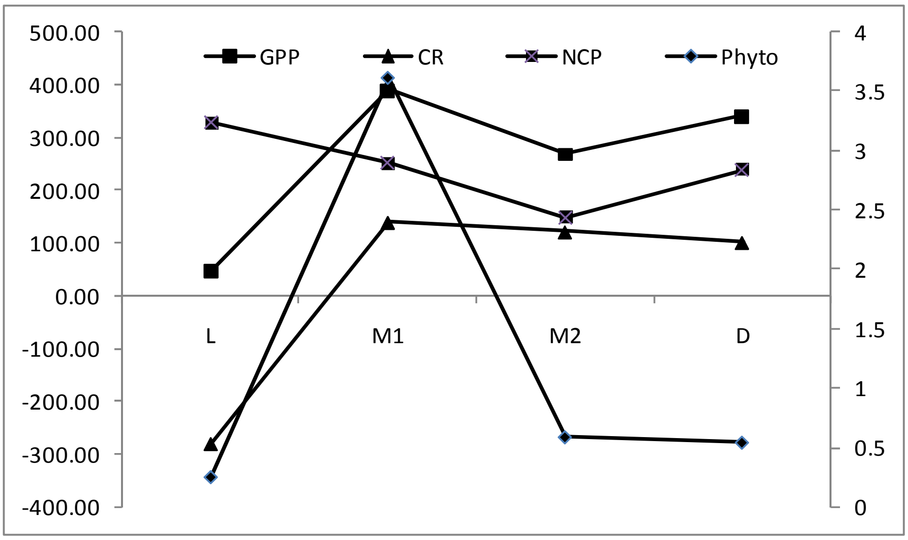

Figure 2: Regional variations of phytoplankton community count (10^6 cell l^{-1}), Gross primary production (GPP), community respiration (CR), and net community production at different water types in El-Mex Bay surface area in summer 2004.

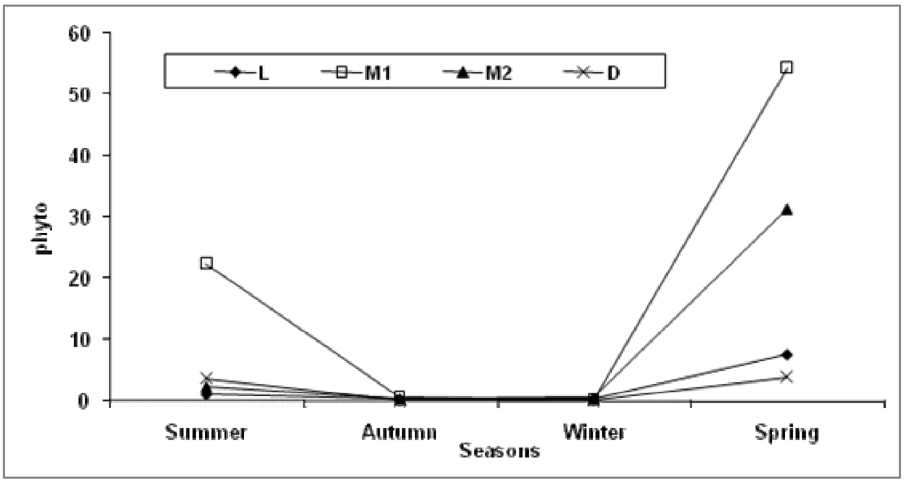

Figure 3: Seasonal variations of total phytoplankton community count (10^6 cell l^{-1}) at different water types in El-Mex Bay during 2003-2004.

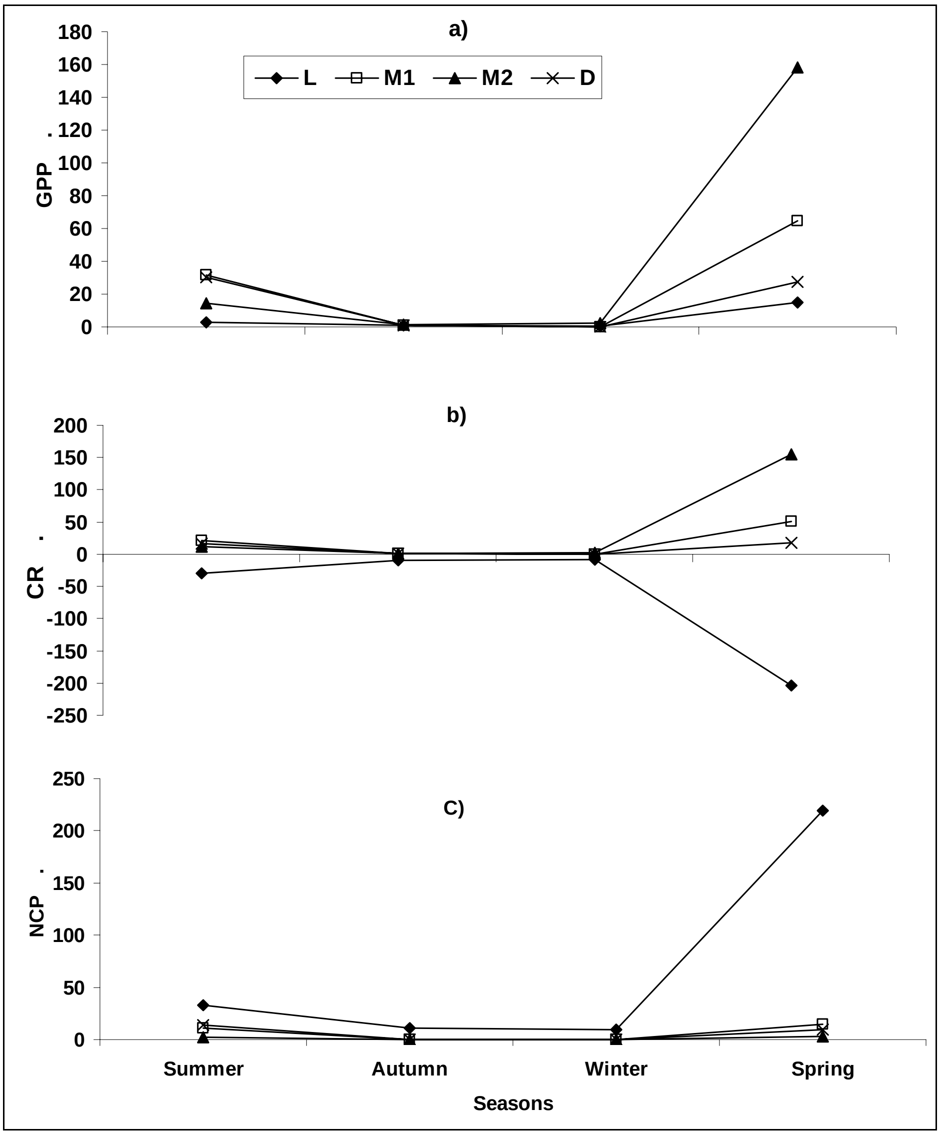

Figure 4: Seasonal variations of daily Gross primary production (GPP), community respiration (CR) net community production (NCP) at different water types at El-Mex Bay. GPP, CR, NCP are in (g C m^{-3} d^{-1}). a) (GPP), b) (CR , C) NCP.

References

American Public Health Association (A.P.H.A.): 1985, Standard method for examination of water and waste water, APHA, AWWA and WPCF, 1268.

Abril, G. and Frankignoulle, M.: 2001, Nitrogen-alkalinity interactions in the highly polluted Scheldt basin (Belgium), *Water Research*, 35(3): pp 844-850.

Bender, M.; Grande, K.; Johnson, K.; Marra, J. and 9 others: 1987, A comparison of four methods for determining planktonic community production. *Limnol. & Oceanogr,* 32: pp 1085–1098.

Brewer, P.G. and Goldman: 1976, Alkalinity changes generated by phytoplankton growth. *Limnol. Oceanogr*. 21, 108-117.

Cai, W.J.; Pomeroy, L.R.; Moran, M.A. and Wang, Y.C.: 1999, Oxygen and carbon dioxide mass balance for the estuarine-intertidal marsh complex of five rivers in the southeastern US. *Limnology and Oceanography* 44: pp 639-649.

Carrillo, C.J.: 2002, Processes controlling carbon dioxide in seawater. PhD Thesis, The University of Hawaii, Oceanography, Graduate Division, 243 p.

Chester, R.: 2001, Dissolved gases in sea water. In Marine Geochemistry. 2nd edition, Black well science, pp165-199.

Duarte, C.M. and Prairie, Y.T.: 2005, Prevalence of heterotrophy and atmospheric CO_2 emissions from aquatic ecosystems. *Ecosystems* 8: pp 862–870.

Dickson A.G.; Afghan J.D. and Anderson G.C.: 2003, Reference materials for oceanic CO_2 analysis: A method for the certification of total alkalinity. *Marine Chemistry,* 80(2-3): pp 185-197.

Eppley, R.W.: 1980, Estimating phytoplankton growth rates in the central oligotrophic oceans. In: Falkowski P.G. (ed.) Primary production in the sea. Plenum, New York, pp 231–242.

Fahmy M.A., Tayel F.T. and Shriadah M.A. (1997). Spatial and seasonal variations of dissolved trace metals in two contaminated basins of the coastal Mediterranean Sea Alexandria, Egypt. *Bull. Fac. Sci. Alex. Univ.*, 37(2): pp 18-29.

Fan, C.; Glibert, P.M. and Barkholder, J.M.: 2003, Characterization of the affinity for nitrogen uptake kinetics and laboratory cultures. Harmful Algae, Elsevier, 2,283-299.

Frankignoulle, M.; Canon, C. and Gattuso, J.-P.: 1994, Marine calcification as a source of carbon dioxide: positive feedback to increasing atmospheric CO_2. *Limnol. and Oceanogr.,* 39: pp 458-462.

Frankignoulle, M.; Bourge, I. and Wollast, R.: 1996a, Atmospheric CO_2 fluxes in a highly polluted estuary (The Scheldt). *Limnol. and Oceanogr.,* 41: pp.365-369

Frankignoulle, M.; Gattuso, J.-P.; Biondo, R.; Bourge, I.; Copin-Montégut, G. and Pichon, M.: 1996b: Carbon fluxes in coral reefs. II. Eulerian study of inorganic carbon dynamics and measurement of airsea CO_2 exchanges. *Marine Ecology-Progress Series,* 145: pp.123-132.

Frankignoulle, M.; Abril, G.; Borges, A.V.; Bourge, I.; Canon, C.; Delille, B.; libert, E. and Theate, J.M.: 1998, Carbon dioxide emission from European estuaries. *Science* 282: pp 434– 436.

Gattuso, J.-P.; Frankignoulle, M. and Wollast, R.: 1998, Carbon and carbonate metabolism in coastal aquatic ecosystems. *Ann. R. Ecol.*, 29: pp405–434.

Gazeau, F.; Duarte, C.M.; Gattuso, J.-P.; Barr´on, C.; Navarro, N.; Ruiz, S.; Prairie, Y.T.; Calleja, M.; Delille, B.; Frankignoulle, M. and Borges, A.V.: 2005a, Whole-system metabolism and CO2 fluxes in a Mediterranean Bay dominated by seagrass beds (Palma Bay, NW Mediterranean). *Biogeosciences*, 2, pp43–60.

Gazeau, F.; Gattuso, J.P.; Middelburg, J.J.; Brion, N.; Schiettecatte, L.S.; Frankignoulle, M. and Borges, A.V.: 2005 b, Planktonic and whole system metabolism in a nutrientrich estuary (the Scheldt estuary). *Estuaries*, 28: pp 868-883.

Gazeau, F.; Middelburg, J.J.; Loijens, M.; Vanderborght, J.-P.; Pizay, M.-D.; Gattuso, J.-P 2007: Planktonic primary production in estuaries: comparison of ^{14}C, O_2 and ^{18}O methods. *Aquat. Microb. Ecol.*, 46: pp 95–106.

Grasshoff, G.: 1976, Method of seawater analysis. Verlag Chemie Weinheim, New York 317p.

Haraldsson, C.; Anderson, L.G.; Hassellöv, M.; Hulth, S. and Olsson, K.: 1997, Rapid, high-precision potentiometric titration of alkalinity in ocean and sediment pore waters. *Deep-Sea Research Part I*, 44: pp 2031-2044.

Heip, C.H.R.; Goosen, N.K.; Herman, P.M.J.; Kromkamp, J.; Middelburg, J.J.; Soetaert, K.; Ansell, A.D.; Gibson, R.N. and Barnes, M.: 1995, Production and consumption of biological particles in temperate tidal estuaries. *Oceanography and Marine Biology: An Annual Review* 33: pp 1–149.

Howarth, R.W. and Michaels, A.F.: 2000, The measurement of primary production in aquatic ecosystems. In: Sala O.E., Jackson R.B., Mooney H.A., Howarth R.W. (eds). Methods in ecosystem science. Springer, New York, pp 72–85.

Langdon, C; Marra, J. and Knudson, C.: 1995, Measurements of net and gross O_2 production, dark O_2 respiration, and ^{14}C assimilation at the marine light-mixed layers site (59°N, 21°W) in the Northeast Atlantic ocean. *J Geophys Res,* 100: pp 6645–6653.

Maestrini, S.Y.; Maija Balode; Christain Bechemin; Ingrida Purina and Uldis Bovata: 1999, Nitrogen as the nutrient limiting the algal growth potential for summer natural assemblage in the Gulf of Riga, Eastern Baltic Sea. Plankton Bio. Ecol. 46(1): 1-7.

Mahmoud, Th.H.; Masoud, M.S. and Shaltout, N.A.: 2005: Physico–Chemical Characteristics of Different water Types in El–Mex Bay, Alexandria, Egypt. MTS/IEEE, Oceans 2005, Washington, D.C.

Parsons, T.R.; Takahashi, M. and Hargrave, B.: 1977, Biological oceanographic processes. *Pergamon Press*, Oxford: pp 1-332.

Peterson, B.J.: 1980, Aquatic primary productivity and the ^{14}C CO_2 method: a history of the productivity problem. *Annu Rev. Ecol. Syst.* 11: pp 359–385.

Randall, J.M. and Day, J.W.: 1987, Effects of river discharge and vertical circulation on aquatic primary production in a turbid Louisiana (USA) estuary. Netherlands *Journal of Sea Research*, 21(3): pp 231-242.

Riley, G.A.: 1939, Plankton studies, II. The Western North Atlantic, May–June, 1939. *J. Mar. Res.* 2:145p.

Sabine, C.L.; Feely, R.A.; Gruber, N.; Key, R.M.; Lee, K.; Bullister, J.L.; Wanninkhof, R.; Wong, C.S.; Wallace, D.W.R.; Tilbrook, B.; Millero, F.J.; Peng, T.H.; Kozyr, A.; Ono, T. and Rios, A.F.: 2004, The oceanic sink for anthropogenic CO_2. *Science*, 305(5682): pp 367–371.

Samir, A.M. and Bader El-Din, A.M.: 2001, Benthic foraminiferal assemblages and morphological abnormalities as pollution proxies in two Egyptian Bays. Marine Micropaleontology, 41: 193-227.

Serret, P.; Robinson, C.; Fernandez, E.; Teira, E. and Tilstone, G.: 2001, Latitudinal Variation of the Balance between Plankton Photosynthesis and Respiration in the Eastern Atlantic Ocean. *Limnol.& Oceanogr*, 46 (7), pp 1642-1652.

Shriadah, M.M.A. and Emara, H.I.: 1996, Heavy metals (iron, manganese, nickel, cadmium, and lead) in the sediments from the Eastern Harbor and El-Mex Bay of Alexandria, Egypt. Proceedings of the Sixth International Conference on Environmental Protection, 21-23 May, Alexandria, 916-927.

Steemann, N.E.: 1952, The use of radiactive carbon (^{14}C) for measuring organic production in the sea. *J. Cons. Perm. Int. Explor. Mer*. 18: pp 117–140.

StricKland, J.D.H. and Parsons, T.R.: 1972, A Practical hand book of sea water analysis. Ottawa, 311p.

Sundquist, E.T. and Plummer, L.N.: 1981, Carbon dioxide in the ocean surface: the homogenous buffer factor. *Science*, 204: pp.1203-1205.

Williams, P.J.; Le, B.; Heinemann, K.R.; Marra, J. and Purdie, D.A.: 1983, Comparison of 14C and O2 measurements of phytoplankton production in oligotrophic waters. Nature, 305: pp 49–50.

Weiss, R.F.: 1974, Carbon dioxide in water and seawater: the solubility of a non-ideal gas. Marine Chemistry 2:203-215.

دورة ثاني أكسيد الكربون البيولوجية في خليج المكس

ا.د. ثناء حنفي محمود – ا.د. ممدوح سعد مسعود – د. نيرة عبد النبي شلتوت – د. نبيلة رجب حسين

المعهد القومي لعلوم البحار والمصايد

تم جمع عينات من المياه السطحية لخليج المكس في أغسطس 2004 للمحطات التالية I، VIII، IX و XII. تمثل هذه العينات نوعيات مختلفة من مياه البحر مثل نوعية المياه التي تتأثر بصرف مصرف العموم وتسمى “L” ومياه البحر المختلطة بمياه الصرف وتنقسم إلي قسمين M_1 و M_2. والنوعية الثالثة هي مياه البحر المخففة “D”.

تم قياس المتغيرات الآتية: درجة الحرارة – الملوحة – الأكسجين الذائب – ثانى أكسيد الكربون والقلوية. تم حساب المتغيرات التالية (GPP) الانتاج الكلى للمجتمع النباتى و (CR) التنفس الكلى للمجتمع النباتى و (NCP) الانتاج الصافى للمجتمع النباتى.

وجد أن أعلى قيمة للانتاج (GPP) الكلى للمجتمع النباتى موجودة في نوعية المياه “M_1” بينما توجد أقل قيمة لها في نوعية المياه “L”.

بينما تتراوح قيم (CR) التنفس الكلى للمجتمع النباتى ما بين 282.3 مجم سم^3/ ساعة إلي 167.38 مجم سم^3/ ساعة في كل من نوعية المياه (L) و (M_2).

وجد أن قيم الانتاج الصافى للمجتمع النباتى قيم (NCP) تتراوح ما بين 147.89 مجم سم^3/ ساعة في نوعية المياه M_2 و327.71 مجم سم^3/ ساعة في نوعية المياه M_1.

تعتبر نوعية المياه “L” من ناحية التغذية خارجية التغذية بينما تعتبر M_1, M_2 و D ذاتية التغذية.