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Estimation of Some Chemical Parameters of River Nile Sediments Exposed to Fish Cages.

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Key words: Fish cages; River Nile; Sediments; Chemical parameters

ABSTRACT

The aim of this study was to assess the environmental impact of cage farm for ongrowing fish (*Oreochromis niloticus*) on the river sediments beneath and adjacent to the cages in El-Bostan region, Damietta Governorate by estimating some of their chemical parameters (organic carbon (OC), total phosphorus (TP) and total nitrogen (TN). In addition, to suggest methods for pollution mitigation in cage culture to be used by cage aquaculture farmers and policy-makers. Sediment samples were collected monthly for one year period, from April 2004 to March 2005, from the riverbed of three points in each sampling site as the following: Before cages (BE), in the cages area (CA) and after the cages (AF). ANOVA (one-way and two-way), Duncan test and Pearson correlation coefficients were calculated to analyze the data statistically. Average contents of all chemical parameters (OC, TP and TN) increased from their lowest values in the BE site to reach their peaks in the CA site, then their values were declined again to be near (slightly higher than) the first lowest values after 2 km in the AF site. The higher annual C/N ratio was recorded in AF site (15.99) followed by CA site (13.37) and BE site (10.11). However, all these ratios were within the favorable ratios in relation to fish production. Seasonal variations were observed for OC in all three sites. Maximum values occurred in winter and spring, which were significantly higher than the values observed in summer and autumn, TP and TN values showed a similar seasonal pattern with minimum values in summer. However they had no pattern in the maximum values. All correlations between the tested parameters were positive and significant.

INTRODUCTION

Cage aquaculture offers a potential source of fish in many areas in the world, particularly where there are plenty of natural water resources, and provides a source of income for poor farmers. So the production of fish in cages has been practiced for years in various countries worldwide and still expanding in many parts of the world;

where over 50 commercially important fish species have been in use for cage aquaculture. Cage aquaculture has several advantages over the conventional land-based aquaculture systems (Beveridge, 1996). Because it uses existing water bodies and requires comparatively low capital investment with simple technology, cage aquaculture has been popular among farmers. Unlike the conventional land-based aquaculture systems cage systems don't use organic and inorganic fertilizers with high nitrogen and phosphorus contents; however, for the same reason, cage systems usually use diets with higher N content. Unlike land-based aquaculture systems cage farms discharge their wastes directly into the environment, most of which are solids or bound to particulate material, and thus subject to sedimentation. Therefore, with the increase in freshwater fish farming (including fish cages), a concern has grown over its possible adverse effect on the aquatic environment. Such effects included accumulation of excreta and waste food and nutrient loading (Yiyong, *et al.*, 2001). In cage cultures, high organic and nutrient loadings generated from feed wastage, excretion and fecal productions are directly discharged into the environment (Waldichuk, 1987; Soley *et al.*, 1994; Wu *et al.*, 1994; Wu, 1995). The origin of any environmental impact derived from intensive cage aquaculture lies mainly in organic matter dumping, nitrogen and phosphorus as a result of fish metabolism (excretion, feces, mucus, etc.) and the food supply (uneaten feed). These causes changes in the physical, chemical and biological characteristics of the receiving environment and are more evident in the riverbed (Dosdat, 2001; Aguado and Garcia, 2004). The main wastes from fish production activities are fish feces and uneaten pelleted feed, these wastes are rich in nitrogen and phosphorus that can readily be converted to forms available for algal growth, thus they have potential to alter the trophic state of the environment (Kelly, 1993). It has been estimated that 11% of the total amount of phosphorus contained in fish feed dissolves in the water, and as much as 66% sinks and accumulates in the sediments (Ackefors and Sodergren, 1985). The other 23% is removed with the fish harvest.

The aim of this study was to assess the environmental impact of cage aquaculture of ongrowing fish (*Oreochromis niloticus*) on the river sediments beneath and adjacent areas to the cages in El-Bostan region, Damietta Governorate, by estimating some of their chemical parameters (organic carbon, total phosphorus and total nitrogen) compared with the same parameters of before, beneath and after the cages site, and to assess the seasonal variations in sediment composition, in the course of a 1-year period. This was conducted as a part of a post doctoral fellowship entitled "Environmental impacts of cage culture for tilapia in Damietta, Egypt" granted and supported by the WorldFish Center. In addition it aimed to suggest methods for pollution mitigation in cage culture to be used by cage aquaculture farmers and policy-makers.

MATERIALS AND METHODS

Description of experimental area

Damietta Governorate has a leadership in many kinds of investment activities one of these activities is fish cage aquaculture. It has the greatest number of fish cages in Egypt, distributed in four districts, as follows: 1) Damietta, 2) Farscour, 3) Kafr Saad, and 4) Al-Zarka districts. El-Bostan region is an area of Damietta district having crowded fish cages, close to each other. Each fish cage farmer establishes his own cage farm in the part of the river which is in front of his home, to ensure security and easy management. People in this area are, mostly, poor and depend in their major diets on fish.

Sampling sites

Sediment samples were collected from three sites as the following: Before cages (BE), in the cages area (CA) and after the cages (AF). The first site (BE) was located in El-Horany region in front of Kafr El-Battekh electric power station which discharges hot water current Table (1) presents data on water characteristics at the three sites. The second site (CA) was located in El-Bostan region; sediment samples were collected underneath three different cage farms (Fig. 1). The third site (AF) was located in an area without any cages before El-Sadd bridge.

Sampling

Sediment samples were collected monthly for one year period, from April 2004 to March 2005, from the riverbed at three points in each sampling site, using Petersen grab soil sampler. The samples were kept tightly closed in polyethylene bags transported directly to the laboratory. Samples were dried in the laboratory and ground to be ready for determination of organic carbon (OC), total phosphorus (TP) and total nitrogen (TN) concentration.

Samples analyses

For OC assessment samples were oxidized with a mixture of potassium dichromate and sulfuric acid. The excess potassium dichromate was titrated with ferrous sulfate (Boyd and Tucker, 1992). TP was determined colorimetrically with ammonium molybdate as coloring reagent after digestion (Van Reeuwijk, 1992). TN was assessed by digesting samples in a mixture of sulfuric acid and selenium, the formed ammonium is measured colorimetrically (Velthorst, 1993). The concentrations of these compounds are expressed as % of sediment dry weight.

Data analyses

Variability in the chemical parameters (OC, TP and TN) was detected by means of a variation coefficient (CV) calculated as "standard deviation / mean" multiplied by 100. Analysis of variance (ANOVA) was used to determine the significance between data and Duncan test were performed for multiple comparisons between sites and/or seasons. Two-way ANOVA was carried out:

$$X_{ij} = \mu + S_i + T_j + S_iT_j + e_{n(ij)}$$

Where X is the dependant variable (OC, TP and TN), μ is the mean, S is the sampling site (three levels), T is season (four levels), e is the residual error and n is the number of replicates. Pearson correlation coefficients were calculated among OC, TP and TN for each sampling site to detect their trends to each other. A significance level of 0.05 was considered in all test procedures. All statistics were performed with the use of (SAS) ® program ver. 9.1 (2005).

RESULTS AND DISCUSSION

Physical observations

The texture and color of the sediment varied with the sampling site, where CA and AF sites were homogenous in texture and composed of fine particles that were dark brown to black, sediment samples from CA site had musty odor. This may be due to accumulation of organic matter derived from unconsumed feed and fish feces underneath cages. While that of BE were sandy and light brown in color.

Chemical parameters patterns

Table (2) shows the mean values with standard deviations and CV of OC in all seasons, followed by the annual average of the three sampling sites. Sediments in the CA site had significantly, the highest content of OC, followed by AF and BE sites in all seasons ($P<0.05$) (Table 2 and Fig. 2). Annual OC average in BE, CA and AF sites were 3.42 ± 2.00, 7.16 ± 2.65 and 4.69 ±1.49 % respectively. This increase in the OC in the cages area was, most probably, due to the fact that cage aquaculture requires large amount of supplied diets which provide the largest source of organic matter in the sediment. This result is in agreement with Weston (1990); Ye *et al.* (1991); Wu (1995); McGhie *et al.* (2000) who reported that substantial quantities of organic matter are applied as food during fish production period. A substantial quantity of food is deposited to the sediment either directly or as fish feces, so organic matter will accumulate under and / or adjacent to fish cages.

In general, nutrients loadings arising form feed supply to fish can be broadly attributed to either or combination of three main factors: (1) feed wastage resulting from poor farming and management practice; (2) poor feed quality (poor stability and high solubility of feed pellets in water); and (3) limited absorption and retention of ingested nutrients resulting from either poor digestibility of food or metabolism of fish (Islam, 2005). Many studies have revealed a high level of organic matter in the sediments directly below fish cages and decreasing concentrations with distance from cages area (Gowen and Bradbury, 1987; Hall *et al.*, 1990; Angel *et al.*, 2000; Schendel *et al.*, 2004).

Percentage of change was calculated for CA and AF sites based on the individual values with the reference of BE site as illustrated in Tables (2, 3 and 4) for OC, TP and TN respectively. The highest OC change was reported in autumn, while the lowest was in spring for both CA and AF sites.

The greatest concentrations of TP were found in the sediments beneath the cages, they were significantly more than that in the AF and BE sites in all seasons except for the summer time with no significant differences between the three sites (Table 3 and Fig. 2). On the other hand, the changes between BE and AF sites were not significant, except in spring, while the mean TP in AF site was significantly higher than that in BE site. The annual average TP in the BE, CA and AF sites were 1.23 ± 0.70, 3.43 ± 2.31 and 1.85 ±0.89 % respectively. Similar results were observed by Temporetti (1998); Temporetti and Pedrozo (2000); Yiyong *et al.* (2001) who found that the significant higher values of TP were in areas immediately under and adjacent to the cage, and the lowest values in the control site (with no cages). Percentage of change were the highest in autumn for both CA and AF sites, however, it had no seasonal trend in its lowest value.

Unlike OC and TP, the mean values of TN in spring and summer were lower in AF site than that in BE site, although not statistically significant. Meanwhile, CA site had significantly the highest TN values, compared to the other two sites except for summer; thought no significant differences was found between the three selected sites. The annual averages of TN were 0.33 ± 0.15, 0.65 ± 0.30 and 0.34 ± 0.12 % for BE, CA and AF sites respectively (Table 4 and Fig. 2). Similar results were recorded by Molina *et al.* (2001) who found that the average nitrogen content of the sediments underneath the cages was significantly greater than the other zones. These elevated values of TP and TN in the cages area could be interpreted with reference to the deposition of fish feces (Yiyong *et al.*, 2001) and uneaten fish feed (Molvaer and Stigebrandt, 1989; Holby and Hall, 1991; Kelly, 1995). Percentages of change for all chemical parameters were highest in autumn and lowest in spring for both sites (CA and AF).

The average levels of all chemical parameters (OC, TP and TN) were increased from their lowest values in BE site to reach their peaks in CA site then their values were reduced again to be near (slightly higher than) the first lowest values after 2 km in AF site (Fig. 2). This phenomenon could be called river self purification. If water current was accelerated by spreading out the same number of cages on larger area (e.g. increasing the distance between cages) or reducing cages number per unit area, this phenomenon will be strengthen and elevated values of organic matter and nutrients will recover to the initial values faster.

Regarding to C/N ratio, there were no significant differences between the three sites in all seasons except for autumn where AF site had higher ratio than that in BE site, while C/N ratio in CA site was not significantly different than either BE nor AF sites (Table 5). The lowest C/N ratios were recorded in autumn in the three sites, while the highest ratios were in summer for CA and AF sites, and in spring for BE site. The higher annual C/N ratio was recorded in AF site (15.99) followed by CA site (13.37) and BE site (10.11), however, all these ratios were within the favorable levels in relation to fish production. Boyd (1990) reported that the most favorable C/N ratio in relation to fish production is 10-15. This present C/N ratio plays an important role in the acceleration of organic matter decomposition and explains the river self purification phenomenon mentioned above. The C/N ratio of organic matter has been widely used as an index of the rate at which organic matter will decompose. Organic matter with a wide C/N ratio, e.g., 80, will decompose much slower than organic matter with a narrow C/N ratio, e.g., 10. (Boyd, 1990).

Many studies have shown that major bulk of the waste food and feces is formed by organic nitrogen compounds. Both of waste food and feces are denser than water and will sink to the sediment in the immediate vicinity of fish cages farm. Large inputs of such particulate organic materials to the sediments have considerable effects on sediment chemistry and the ecology of benthic organisms (Gowen and Bradbury, 1987). Enhanced levels of dissolved organic phosphate have resulted in eutrophication (Cloern, 2001; Islam and Tanaka 2004) and phosphate released from fish cages may have similar effects (Porrello *et al.*, 2003).

Many studies have revealed that the mean values of OC, TP and TN beneath the cages were always higher compared to its values in other sites. However, Aguado and Garcia (2004) found that little change in the sediment chemistry associated to the fish cage farm waste load was noticed. They attributed this phenomenon to the physical conditions including depth (36 m), current speed (7.85 cm/s) and the short life of fish farm (this study was in the first year of the operation of the farm). They added that, probably, if the farm continues to operate, sediment changes in its vicinity will become more potent.

Generally, so far, there is no regulation around the world as to the allowable limit of N and P discharge from fish culture to the environment. At the same time, any information or experimental evidence is hardly available as to the assimilative capacity of the environment (Islam, 2005).

Table (6) shows the results of the two-way ANOVA performed to analyze the relationships among chemical parameters (OC, TP and TN) and main effects (site regardless season and season regardless site) and their interaction. The results showed highly significant differences of all sources of variation (the model, main effects and the interaction) for all chemical parameters except for the interaction between site and season in OC, that was significant (P = 0.02). This means the concentrations of the studied chemical compounds were significantly affected by either site or season and their interaction.

Seasonal variations

Seasonal variations were observed for OC in all the three sites. Maximum values occurred in winter and spring, which were significantly higher than values observed in summer and autumn. This trend, however was less apparent in the CA site, there were no significant difference between winter, spring and autumn values, whereas all of them are significantly higher than the summer value. Generally, the minimum values of OC were observed in summer in all sites except for BE site recorded in autumn (Table 7 and Fig. 3). TP and TN values showed a similar seasonal pattern with minimum values in summer. However they had no pattern in the maximum values.

The lower values of OC and the two nutrients (TP and TN) which were found in summer could refer to the lesser amount of uneaten food, as a result of the increased activity of fish in summer and to increased water temperature (30.58 ^{o}C), which facilitates their removal. Boyd (1990) stated that decomposition of organic matter is favored by warmth. Rates of decomposition generally increase over the range of 5-35 ^{o}C. A temperature increase of 10 ^{o}C often doubles the rate of decomposition (Q_{10}=2). Increased temperature enhanced greatly the decomposition of organic matter (Huang *et al*., 2002).

Similar trends were found by Gilbert *et al.* (1997), although a different one has been reported by Karakassis *et al*. (1998). These differences may be due to different management systems of the farms and/or different farm conditions.

Figure (4) shows the correlation coefficients (r) for OC vs. TP, OC vs. TN and TP vs. TN in BE, CA and AF sites. All correlations between all parameters were positive and there is a combination of significant and highly significant correlations between all parameters in all sites, except for TP and TN in AF site that was positive but not significant (r = 0.44). Correlation coefficients ranged between 0.60 and 0.88 for all parameters, which means that all sediment chemical parameters are related to each other, indicating that they might come from the same source (fish feed and feces).

CONCLUSION

Based on the obtained results, it can be concluded that: average levels of all chemical parameters (OC, TP and TN) increased from their lowest values in the BE site to reach their peaks in the CA site, as a result of uneaten feed and fish feces accumulated under cages. Their values were then declined again to be near (slightly higher than) the first lowest values after 2 km in the AF site. This phenomenon could be called river self purification, however all C/N ratios of all sites are within the favorable C/N ratios in relation to fish production, this suitable C/N ratio plays an important role in the acceleration of organic matter decomposition.

RECOMMENDATIONS

To avoid the undesirable effects of the organic sediments and nutrient accumulation, water current should be accelerated by keeping 50 m free from cages around each cage. Moreover, fish feeds should be used wisely (good quality without waste remains). Furthermore, it is recommend a mechanical withdrawn of the sediment to get rid of OC, TP and TN accumulation under cages then it could be used as a rich agriculture organic fertilizer. In other words cage aquaculture situation needs to be critically reviewed to be sustainable and not exceeding the river carrying capacity in order to gain their advantages and avoid their disadvantages.

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ARABIC SUMMARY

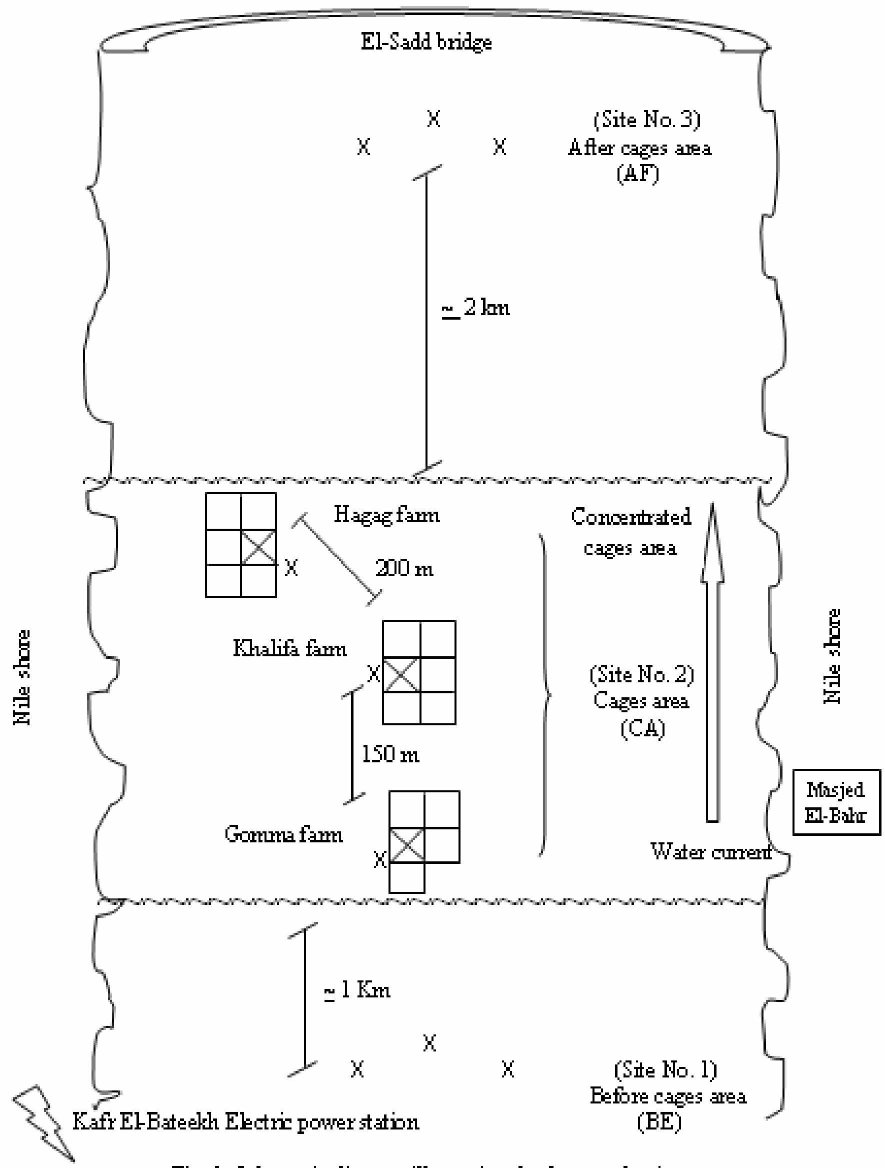


Fig. 1. Schematic diagram illustrating the three study sites

X is water and sediments sampling sites

Table (1) Preliminary data of water characteristics at the study sampling sites

Item	Sampling sites		
	BE	CA	AF
Distance from cages area (km)	-1	0	+2
Average water temperature in summer (^{o}C)	30.99	30.58	30.83
Average water temperature in winter (^{o}C)	19.14	18.73	18.80
Average water dissolved oxygen (mg/l)	4.60	2.90	3.99
Average water current (cm/s)	5.88	2.78	2.23
Average water total phosphorus (mg/l)	0.175	0.215	0.207
Average water total nitrogen (mg/l)	1.582	1.699	1.571

Table (2) Mean seasonal values ± standard deviation of sediment organic carbon (%) for the three tested sites and percentage of change for CA and AF sites with reference to BE site.

Season	Site	Mean ± SD	CV (%)	Percentage Change
Spring	BE	5.48 b ± 0.44	(7.9)	-----
	CA	7.70 a ± 0.67	(8.7)	40.56
	AF	5.77 b ± 0.98	(16.9)	5.92
Summer	BE	1.88 b ± 0.20	(10.5)	-----
	CA	4.30 a ± 0.84	(19.6)	132.19
	AF	3.37 a ± 1.20	(35.6)	77.68
Autumn	BE	1.49 c ± 1.68	(112)	-----
	CA	7.08 a ± 2.46	(34.7)	582.22
	AF	4.10 b ± 1.54	(37.5)	327.66
Winter	BE	4.85 b ± 0.75	(15.4)	-----
	CA	9.53 a ± 2.85	(29.9)	99.89
	AF	5.52 b ± 0.86	(15.5)	14.80
Annual Average	BE	3.42 c ± 2.00	(58.5)	-----
	CA	7.16 a ± 2.65	(37.0)	197.69
	AF	4.69 b ± 1.49	(31.8)	96.90

Means in the same season with similar letter are not significantly different (Duncan test, P<0.05)

Table (3) Mean seasonal values ± standard deviation of sediment total phosphorus (%) for the three tested sites and percentage of change for CA and AF sites with reference to BE site.

Season	Site	Mean ± SD	CV (%)	Percentage Change
Spring	BE	1.67 b ± 0.45	(27.1)	-----
	CA	3.50 a ± 0.44	(12.6)	121.36
	AF	2.61 c ± 0.38	(14.5)	64.16
Summer	BE	0.70 a ± 0.15	(21.9)	-----
	CA	0.90 a ± 0.30	(33.0)	36.65
	AF	0.76 a ± 0.18	(24.0)	18.76
Autumn	BE	0.81 b ± 0.85	(104.7)	-----
	CA	5.68 a ± 3.18	(56.1)	627.20
	AF	2.01 b ± 0.76	(37.9)	339.29
Winter	BE	1.73 b ± 0.49	(28.6)	-----
	CA	3.65 a ± 0.58	(15.8)	136.72
	AF	2.03 b ± 0.81	(39.7)	15.57
Annual Average	BE	1.23 b ± 0.70	(57.4)	-----
	CA	3.43 a ± 2.31	(67.4)	213.24
	AF	1.85 b ± 0.89	(47.8)	99.45

Means in the same season with similar letter are not significantly different (Duncan test, P<0.05)

Table (4) Mean seasonal values ± standard deviation of sediment total nitrogen (%) for the three tested sites and percentage of change for CA and AF sites with reference to BE site.

Season	Site	Mean ± SD	CV (%)	Percentage Change
Spring	BE	0.42 b ± 0.08	(18.6)	-----
	CA	0.62 a ± 0.05	(7.4)	49.20
	AF	0.37 b ± 0.11	(29.7)	-7.20
Summer	BE	0.24 a ± 0.12	(47.3)	-----
	CA	0.30 a ± 0.24	(79.2)	18.09
	AF	0.23 a ± 0.18	(77.3)	28.29
Autumn	BE	0.25 b ± 0.21	(83.6)	-----
	CA	0.88 a ± 0.27	(30.8)	397.18
	AF	0.36 b ± 0.05	(13.6)	119.85
Winter	BE	0.39 b ± 0.08	(19.4)	-----
	CA	0.80 a ± 0.21	(26.7)	105.14
	AF	0.39 b ± 0.06	(15.9)	1.42
Annual Average	BE	0.33 b ± 0.15	(45.1)	-----
	CA	0.65 a ± 0.30	(46.2)	142.40
	AF	0.34 b ± 0.12	(36.3)	35.59

Means in the same season with similar letter are not significantly different (Duncan test, P<0.05)

Table (5) Mean seasonal values ± standard deviation of sediment C/N ratio for the three tested sites.

Season	Site	Mean ± SD	CV (%)
Spring	BE	13.44 a ± 2.64	(19.7)
	CA	12.6 a ± 1.86	(14.8)
	AF	16.45 a ± 4.69	(28.5)
Summer	BE	9.07 a ± 3.81	(42.1)
	CA	20.32 a ± 9.78	(48.1)
	AF	21.26 a ± 13.92	(65.5)
Autumn	BE	5.29 b ± 3.97	(75)
	CA	8.01 ab ± 1.45	(18.1)
	AF	11.99 a ± 5.75	(48)
Winter	BE	12.64 a ± 2.33	(18.5)
	CA	12.55 a ± 4.88	(38.9)
	AF	14.25 a ± 1.96	(13.8)
Annual Average	BE	10.11 b ± 4.49	(44.5)
	CA	13.37 ab ± 6.90	(51.6)
	AF	15.99 a ± 8.20	(51.3)

Values in the same season with similar letter are not significantly different (Duncan test, P<0.05)

Table (6) Two-way analyses of variance for organic carbon, total phosphorus and total nitrogen.

Parameter	ANOVA two-way (model)	Site Effect (T)	Season Effect (S)	Site*Season Effect (S*T)
OC (%)	$F_{(11,60)} = 15.90$ $P<0.001$	$F_{(2,60)} = 42.52$ $P<0.001$	$F_{(3,60)} = 24.45$ $P<0.001$	$F_{(6,60)} = 2.76$ $P = 0.02$
TP (%)	$F_{(11,60)} = 12.04$ $P<0.001$	$F_{(2,60)} = 27.81$ $P<0.001$	$F_{(3,60)} = 14.19$ $P<0.001$	$F_{(6,60)} = 5.71$ $P<0.001$
TN (%)	$F_{(11,60)} = 11.11$ $P<0.001$	$F_{(2,60)} = 32.54$ $P<0.001$	$F_{(3,60)} = 10.73$ $P<0.001$	$F_{(6,60)} = 4.16$ $P = 0.002$

Values between brackets are degrees of freedom for error and source of variation.

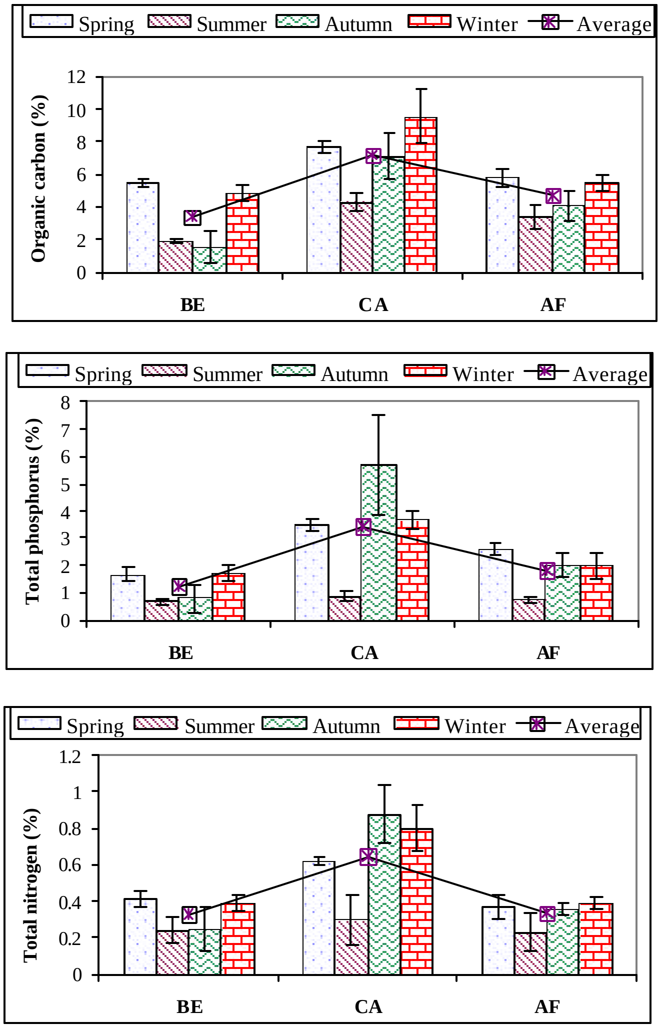


Fig. 2. Mean values with standard error bars and annual average concentrations of organic carbon, total phosphorus and total nitrogen througho ut different seasons in the three tested sites

Table (7) Seasonal variations of sediment organic carbon, total phosphorus and total nitrogen (%) in the three tested sites.

Season	BE	CA	AF
Organic carbon (%)			
Spring	5.48 [a]	7.70 [a]	5.77 [a]
Summer	1.88 [b]	4.30 [b]	3.37 [b]
Autumn	1.49 [b]	7.08 [a]	4.10 [b]
Winter	4.85 [a]	9.53 [a]	5.52 [a]
Total phosphorus (%)			
Spring	1.67 [a]	3.50 [b]	2.61 [a]
Summer	0.70 [b]	0.90 [c]	0.76 [b]
Autumn	0.81 [b]	5.67 [a]	2.01 [a]
Winter	1.73 [a]	3.65 [b]	2.03 [a]
Total nitrogen (%)			
Spring	0.42 [a]	0.62 [a]	0.37 [ab]
Summer	0.24 [b]	0.30 [b]	0.23 [b]
Autumn	0.25 [ab]	0.88 [a]	0.36 [ab]
Winter	0.39 [ab]	0.80 [a]	0.39 [a]

Values in the same column with similar letter are not significantly different (Duncan test, P<0.05)

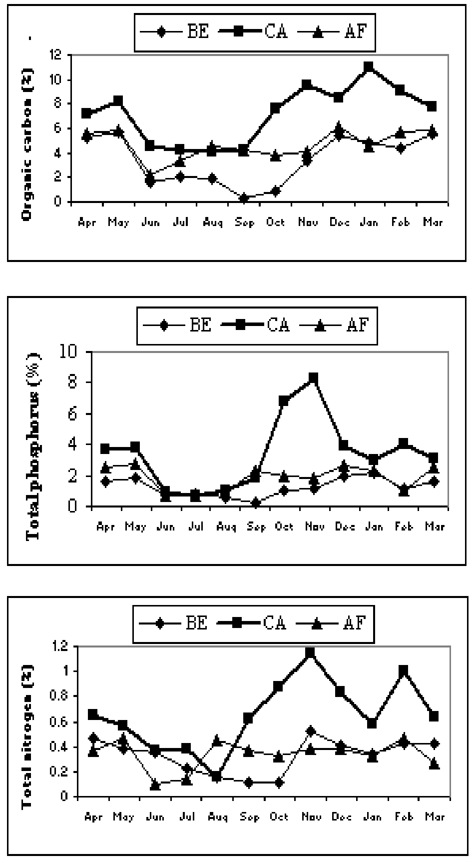
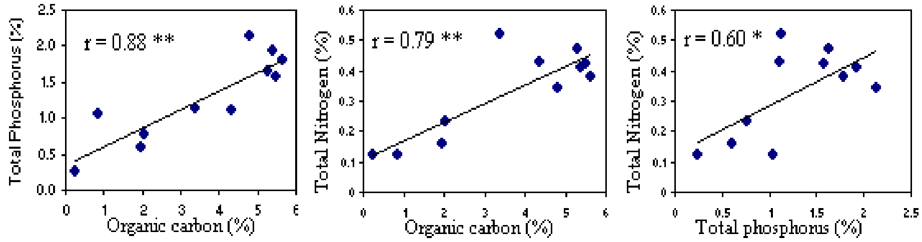
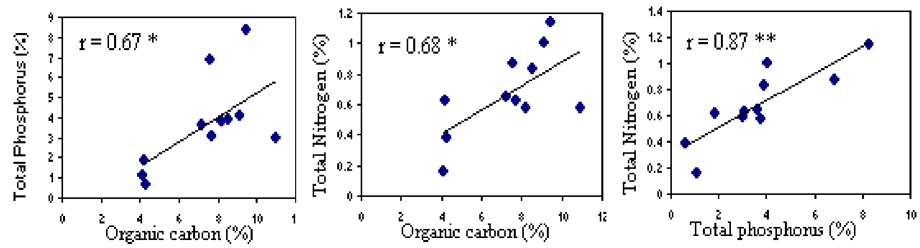


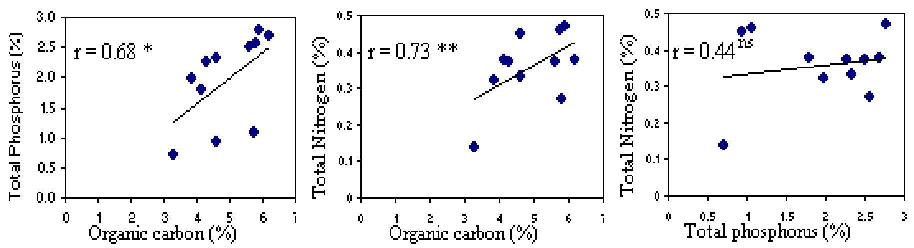
Fig. 3. Monthly fluctuation of organic, carbon total phosphorus and total nitrogen in the BE, CA and AF sites.



Before cages (BE)



Cages area (CA)



After cages (AF)

Fig. 4. Relationship between average sediment content of organic carbon vs. total phosphorus, organic carbon vs. total nitrogen and total phosphorus vs. total nitrogen in the three tested sites.