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Ecological Monitoring of Mediterranean *Solea Aegyptiaca* Transplanted into Lake Qaroun, Egypt

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Abstract: *Solea aegyptiaca* was successfully transplanted into Lake Qaroun from the Mediterranean sea to improve the yield of its original strain in the lake and this process continued at different time intervals. Salinity of the lake increases during summer season due to high evaporation rates and changes in the inflow regime. The deterioration of water resources in the lake during the summer season is considered as a serious threat to the aquatic life. Therefore, this study was carried out during summer and beginning of autumn seasons where fish are exposed to severe alterations in the aquatic environment. Water quality indices of Lake Qaroun showed significant differences and the studied water heavy metals (Cu^{+2}, Zn^{+2}, Mn^{+2} and Pb^{+2}) were in accordance with values of residual heavy metals in tissues, the bioaccumulation process showed also specificity to fish tissues. Histological sections in gills, liver and kidneys of *S. aegyptiaca* collected during June showed much more improvement than samples collected during other months. Histopathological alterations and clear damages were obvious in samples collected during late summer and beginning of autumn (July, August and September) generally in accordance with the results of residual heavy metals in water and tissues. Moreover, the results revealed significant differences in values of growth indices, meat quality, blood parameters and plasma constituents of *S. aegyptiaca* collected from Lake Qaroun. Generally, the values were deteriorating during late summer and showed much more improvement during June and September.

Key words: *Solea aegyptiaca,* Lake Qaroun, fish transplantation, heavy metals, bioaccumulation.

INTRODUCTION

Lake Qaroun is environmentally important as a wetland of international importance and it is used to support a major fishery. It lies in an arid region, occupying the deepest part of El-Fayoum Province in the Western Desert of Egypt and lies about 85 kilometers to the southwest of Cairo. Due to its unique position, it is considered a closed basin used as a general reservoir for agricultural and sewage drainage water from El-Fayoum Province, as well as, the drainage of the fish farms (Mansour and Sidky, 2002, 2003; Ali and Fishar, 2005). The lake receives this agricultural and sewage drainage water through a system of twelve drains. Most of the drainage water reaches the lake through two main drains, El-Batts (at the northeastern corner) and El-Wadi (near mid point of the southern shore), whereas there are minor drains that pour its drainage water into the lake by means of hydraulic pumps but in small amounts and add comparatively little water to the lake (Ali and Fishar, 2005). Thus the present study was conducted at the outlets of these two main drains. Abd-Ellah (2009) indicated that the discharge water via these main drains represents the major part of the inputs (85.88%) while evaporation represents one of the largest components of the water outputs (97.39%) which reach its maximum values during summer season.

History of Lake Qaroun witnessed several drastic changes affecting its role as economic potential site for living natural resources. The main reason came from gradually increasing salinity over the last century. Two important factors had affected this increase in salinity; the first depends on the input of drainage water (controlled by irrigation practices). The second is the subtropical climate of the lake leading to high temperature and seasonal fluctuations in rate of water evaporation (Anwar *et al.,* 2001). Abdel-Satar *et al.* (2010) reported a seasonal fluctuation in water salinity ranging from 23.46 to 39.01 g/l during 2006. Fathi and Flower (2005) postulated that it reached an average of 43.9 g/l during summer seasons and showed sharp decrease during winter seasons. Extensive evaporation of water from such closed ecosystem increases concentration of salts, heavy metals, pesticides and other pollutants. Consequently, this changes the quality of water and affects biology of the lake (Ali *et al*., 2008). Being located in an arid area with high evaporation

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rate (~7mm/h), freshwater input does not compensate for seasonal evaporation and salinity increases. The deterioration of water resources in the lake during the summer season is considered as a serious threat to the aquatic life (Mansour and Sidky, 2002; Fathi and Flower, 2005).

The gradual increase of water salinity led to disappearance of some fish species with low halotolerance such as *Lates niloticus, Clarias anguillaris, Labeo niloticus, Barbus bynni* and *Oreochromis niloticus*. Therefore, to compensate this loss of fish stock, the lake was periodically stocked under governmental supervision with fish fries such as mullets (*Mugil cephalus* and *Liza ramada*) and *Solea aegyptiaca* (El-Shabrawy and Belmonte, 2004). So, the interest of studying Lake Qaroun arises from the fact that it has been undergoing pronounced ecological changes that led to severe decrease in quantity and quality of fish stock and the transplantation of fish fry is an important solution in order to overcome the problems of diminishing fish yield in the lake. Therefore, this study was carried out during the summer and beginning of autumn seasons (June, July, August and September, 2007) at which the transplanted species; *S. aegyptiaca* are exposed to severe alterations in the aquatic environment.

MATERIALS AND METHODS

Water Sampling:

Duplicates of water samples were taken with a water sampler from two localities, 200-500 meters from the shore at the outlet of each of the two main drainage canals, El-Batts and El-Wadi between 10.00 and 12.00am at a depth of 30 cm below the water surface. Water temperature, pH and dissolved oxygen were immediately measured using Corning Checkmate II multi-parameter meter while water salinity, total hardness and total alkalinity were measured according to APHA (1989).

Fish Sampling:

Fish were sampled from the same water sampling sites with the help of local fishermen. Individual fish were weighed (g) and measured for total length (cm). Condition factor (*CF*) and Hepato-somatic index (*HSI*) were calculated according to Schreck and Moyle (1990) as:

$CF = Weight\ (g)/Length^3\ (cm)\ X100.$
$HSI = Weight\ of\ the\ liver\ (g)/Total\ fish\ weight\ (g)\ X100$

Muscle samples were analyzed for muscle water content, muscle ash percentage (Sidwell *et al*., 1970), muscle total protein (Josyln, 1950) and muscle total lipids (AOAC, 1980). Liver water content was determined according to Sidwell *et al.* (1970).

Atomic absorption spectrophotometer (Model, Perkin Elmer-2280) was used to measure water heavy metals and the residual heavy metals (Cu^{+2}, Zn^{+2}, Mn^{+2} and Pb^{+2}) in gills, liver, kidneys, skin and muscles of *S. aegyptiaca* (APHA, 1989). Gills, liver and kidneys of *S. aegyptiaca* were preserved in Bouin's fixative for histological examination. Tissues were processed, sectioned at 4µm and then stained using Haematoxylin and Eosin (Bernet *et al*., 1999).

Haematology:

Blood was withdrawn from the caudal vein of fish using sodium citrate as anticoagulant. The red blood cells (*RBCs*) and white blood cells (*WBCs*) were manually counted using improved Neubauer Haemocytometer. Values were expressed as number of cells/mm. Haematocrit (*Ht*) was determined using duplicates of microhaematocrit tubes using haematocrit centrifuge at 3000 rpm for 15 minutes. The haemoglobin concentration (*Hb*) was estimated using cyanomethaemoglobin method (Blaxhall and Daisley, 1973). The red cell indices; mean corpuscle volume (*MCV*), mean corpuscle haemoglobin (*MCH*) and mean corpuscle haemoglobin concentration (*MCHC*) were calculated using standard formulae (Coles, 1986).

Plasma Biochemistry:

Blood samples were centrifuged to get plasma for determination of glucose (Trinder, 1969), total lipids (Frings and Dunn, 1970), total protein (Bradford, 1976), albumin (Dumas and Biggs, 1972), creatinine (Henry *et al*., 1974), uric acid (Artiss and Entwistle, 1981) and the activities of aminotransferases (*AST* and *ALT*) (Reitman and Frankel, 1957) using enzymatic-colorimetric methods by means of commercial kits (Sigma Diagnostics, Egypt). The globulin content (G) was estimated by subtracting the albumin content (A) from total protein content then A/G ratio was calculated.

Statistical Analysis:

Data are represented as means of eight samples ±S.E. Results were statistically analyzed using analyses of variance (F-test) followed by Duncan's multiple range test to evaluate difference in means at $P<0.01$ using Statistical Analysis System, version 9.1 (SAS, 2006).

RESULTS AND DISCUSSION

Water quality indices showed significant differences in values of water temperature, pH, dissolved oxygen, total hardness, total alkalinity, salinity and water heavy metals (Tables 1 and 2).

The highest values of total alkalinity, total hardness and salinity were recorded during August followed by that recorded during July and the lowest values were recorded during September. The highest copper, zinc, manganese and lead concentrations were recorded in water samples collected from the lake during August followed by that collected during July and June respectively. Manganese and lead concentrations exceeded the guideline values proposed by WHO (2008) during August and July months.

Table 1: Water quality.

Variable	Temperature (°C)	pH	Dissolved oxygen (mg/l)	Total Hardness as $CaCO_3$ (mg/l)	Total alkalinity as $CaCO_3$ (mg/l)	Salinity (g/l)
June	27.13 ±0.43^{C}	8.68 ±0.05^{A}	6.55 ±0.14^{C}	813.87 ±2.44^{C}	392.75 ±2.16^{C}	39.88 ±0.28^{C}
July	29.50 ±0.42^{B}	8.47 ±0.02^{B}	7.18 ±0.18^{B}	840.25 ±2.93^{B}	406.0 ±1.10^{B}	41.88 ±0.27^{B}
August	31.50 ±0.41^{A}	8.43 ±0.02^{B}	7.93 ±0.14^{A}	861.0 ±0.59^{A}	418.0 ±1.76^{A}	43.23 ±0.20^{A}
September	28.87 ±0.28^{B}	8.20 ±0.02^{C}	6.05 ±0.04^{D}	803.25 ±1.08^{D}	373.25 ±1.75^{D}	38.87 ±0.27^{D}
F-value	21.0*	41.0*	36.50*	169.30*	125.0*	55.90*

Different case letters or * indicate significant differences ($P<0.01$).

Table 2: Heavy metal concentrations in water samples (mg/l).

Variable	Copper	Zinc	Manganese	Lead
June	0.125 ±0.011^{C}	0.009 ±0.001^{C}	0.350 ±0.013^{C}	0.007 ±0.001^{C}
July	0.220 ±0.008^{B}	0.031 ±0.001^{B}	0.460 ±0.012^{B}	0.025 ±0.003^{B}
August	0.300 ±0.005^{A}	0.042 ±0.001^{A}	0.670 ±0.020^{A}	0.046 ±0.002^{A}
September	0.090 ±0.030^{D}	0.007 ±0.001^{C}	0.295 ±0.004^{D}	0.004 ±0.001^{D}
F-value	29.30*	782.60*	172.30*	106.0*

Guideline values of the measured heavy metals in water according to WHO (2008):
Copper = 2 mg/l. Manganese = 0.4 mg/l. Lead = 0.01 mg/l.
No health-based guideline values have been proposed for zinc in water according to WHO (2008).
Different case letters or * indicate significant differences ($P<0.01$).

The distribution pattern of the studied heavy metals (Cu^{+2}, Zn^{+2}, Mn^{+2} and Pb^{+2}) followed different sequences in the studied organs (Tables 3, 4, 5 and 6). All values were significantly higher in tissues of *S. aegyptiaca* collected at the end of summer season (August) followed by July and lastly during September (beginning of autumn) in comparison with the least bioaccumulated heavy metals in tissues of fish collected from the lake during June. Zinc and lead concentrations exceeded the upper levels of intake in edible tissues (muscles) proposed by WHO (2008) during August and July months. The present investigation was confirmed by histological studies of some vital organs (gills, liver and kidneys) of *S. aegyptiaca* (Photomicrographs 1, 2 and 3). Histopathological alterations and clear damages were obvious in gills, liver and kidneys of the studied sole fish collected from the lake during July, August and September.

Table 3: Copper concentrations in some selected organs (mg/kg dry weight) of *S. aegyptiaca*.

Variable	Gills	Liver	Kidneys	Skin	Muscles
June	4.53 ±0.28^{D}	63.43 ±5.16^{D}	15.46 ±1.12^{D}	1.26 ±0.16^{D}	1.51 ± 0.19^{C}
July	11.33 ±0.06^{B}	105.55 ±3.25^{B}	21.39 ±0.17^{B}	4.13 ±0.09^{B}	2.85 ±0.13^{B}
August	15.59 ±0.21^{A}	190.24 ±2.22^{A}	24.74 ±0.64^{A}	5.05 ±0.03^{A}	5.59 ±0.62^{A}
September	6.86 ±0.03^{C}	76.72 ±1.92^{C}	18.31 ±1.08^{C}	1.62 ±0.14^{C}	1.18 ±0.12^{C}
F-value	756.0*	283.0*	22.0*	250.0*	35.0*

Upper level of intake of copper in food for human consumption according to WHO (2008) = 10 mg/day.

Table 4: Zinc concentrations in some selected organs (mg/kg dry weight) of *S. aegyptiaca*.

Variable	Gills	Liver	Kidneys	Skin	Muscles
June	84.94 ±0.21^{C}	28.27 ±0.95^{D}	151.75 ±4.21^{D}	52.51 ±1.12^{D}	13.04 ±0.12^{D}
July	137.67 ±0.27^{B}	57.58 ±3.22^{B}	185.04 ±1.88^{B}	91.85 ±0.34^{B}	20.31 ±0.69^{B}
August	157.64 ±3.29^{A}	75.90 ±0.83^{A}	214.03 ±7.02^{A}	119.64 ±2.62^{A}	27.92 ±0.82^{A}
September	87.29 ±0.25^{C}	38.12 ±0.11^{C}	172.51 ±1.62^{C}	58.91 ±1.48^{C}	15.03 ±0.09^{C}
F-value	482.0*	149.0*	37.0*	373.0*	151.0*

Upper level of intake of zinc in food for human consumption according to WHO (2008) = 15-20 mg/day.

Table 5: Manganese concentrations in some selected organs (mg/kg dry weight) of *S. aegyptiaca*.

Variable	Gills	Liver	Kidneys	Skin	Muscles
June	9.62± 0.27^{D}	2.95± 0.25^{C}	4.89± 0.24^{B}	19.11 ±2.30^{C}	0.27± 0.02^{C}
July	29.14± 0.55^{B}	4.35 ±0.12^{B}	9.36± 1.09^{B}	27.32± 0.28^{B}	0.49± 0.02^{B}
August	34.96 ±0.72^{A}	5.47± 0.23^{A}	33.04± 4.67^{A}	33.02± 0.93^{A}	0.89± 0.03^{A}
September	19.04 ±1.09^{C}	3.38 ±0.15^{C}	4.55± 0.45^{B}	19.87± 1.87^{C}	0.26± 0.03^{C}
F-value	241.0*	33.0*	31.0*	18.0*	190.0*

Upper level of intake of manganese in food for human consumption according to WHO (2008) = 11 mg/day.

Table 6: Lead concentrations in some selected organs (mg/kg dry weight) of *S. aegyptiaca*.

Variable	Gills	Liver	Kidneys	Skin	Muscles
June	0.86 ±0.08^{D}	0.31± 0.04^{C}	1.05± 0.03^{C}	0.32 ±0.01^{D}	0.20 ±0.03^{C}
July	3.21± 0.11^{B}	0.68 ±0.02^{B}	6.16 ±0.26^{B}	0.57± 0.01^{B}	0.64 ±0.03^{B}
August	4.64± 0.17^{A}	1.38 ±0.09^{A}	9.23± 0.56^{A}	0.89± 0.03^{A}	1.19± 0.12^{A}
September	1.55 ±0.05^{C}	0.37± 0.04^{C}	1.36± 0.01^{C}	0.46± 0.01^{C}	0.25 ±0.04^{C}
F-value	243.0*	77.0*	164.0*	268.0*	50.0*

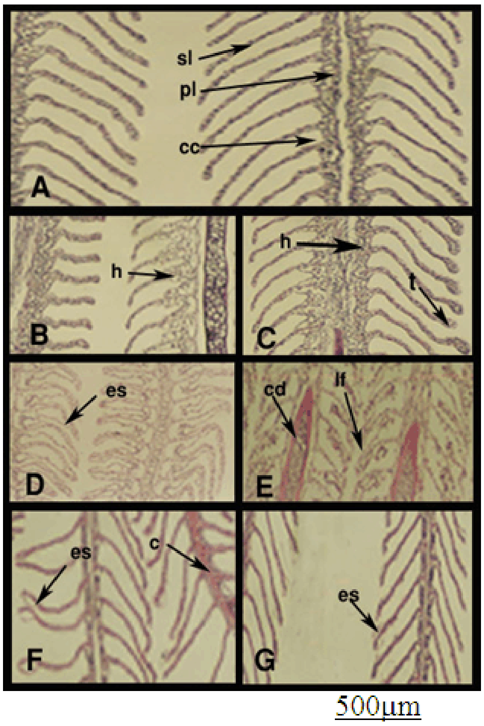
Upper level of intake of lead in food for human consumption according to WHO (2008) = 0.25 mg/day.
Different case letters or * indicate significant differences ($P < 0.01$).

There was a significant increase in fish body weight and total length along the study period indicating the growth of the transplanted fish. There was a decrease in values of condition factor associated with an increase in liver water content in fish collected during July and August in comparison with that of fish collected during the other two months (Table 7).

Table 7: Morphological parameters and liver water content of *S. aegyptiaca.*

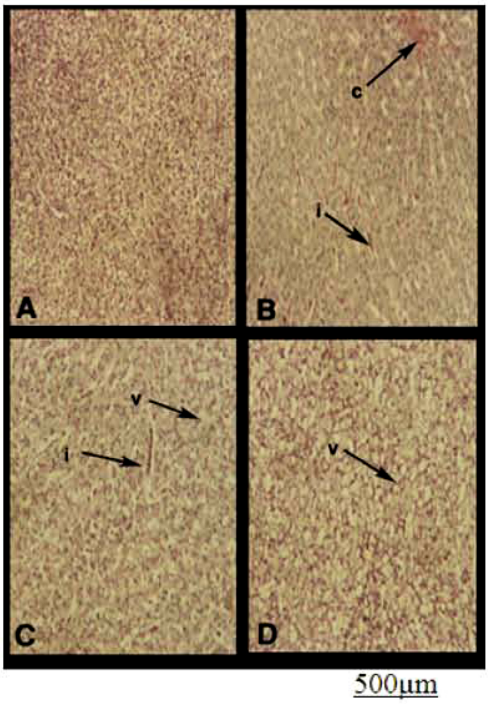
Variable	Body weight (g)	Total length (cm)	Condition factor	Hepato-somatic index	Liver water content (%)
June	27.91 ±0.56^{D}	14.85± 0.12^{D}	0.85± 0.02^{A}	1.39± 0.19$^{A/B}$	67.42± 1.09^{B}
July	30.83 ±0.83^{C}	15.97 ±0.09^{C}	0.76 ±0.02^{B}	1.04 ±0.06^{B}	72.62± 0.08^{A}
August	34.67 ±0.44^{B}	16.63± 0.07^{B}	0.75± 0.01^{B}	1.05 ±0.09^{B}	72.77 ±0.28^{A}
September	42.89 ±1.29^{A}	17.37± 0.25^{A}	0.82± 0.01^{A}	1.45 ±0.09^{A}	64.79 ±0.70^{C}
F-value	58.66*	48.75*	8.17*	3.45*	35.56 *

Different case letters or * indicate significant differences ($P < 0.01$).

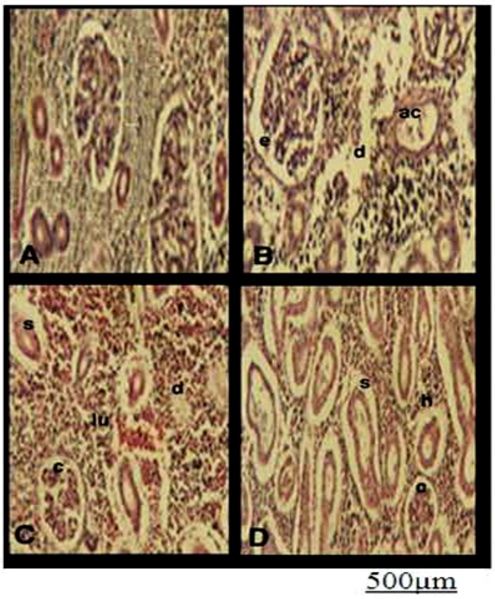


Photomicrograph 1: Histological sections in gills of *S. aegyptiaca* collected from Lake Qaroun during June (A), July (B&C), August (D&E) and September (F&G).

sl, secondary lamellae; **pl**, primary lamellae; **cc**, chloride cell; **h**, hyperplasia; **lf**, lamellae fusion; **es**, epithelium separation; **c**, congestion; **cd**, cartilage deformation; **t**, telangiectasis. (H&E stains).



Photomicrograph 2: Histological sections in liver of *S. aegyptiaca* collected from Lake Qaroun during June (A), July (B), August (C) and September (D).
c, congestion; **v**, vacuolation; **i**, infiltration of blood cells. (H&E stains).



Photomicrograph 3: Histological sections in kidneys of *S. aegyptiaca* collected from Lake Qaroun during June (A), July (B), August (C) and September (D).
e, edema; **d**, degeneration of hyaline droplets; **ac**, accretion of connective tissue; **s**, swelling of epithelial cells; **c**, collapse of glomeruli; **lu**, leukocytes releases; **h**, hyperplasia. (H&E stains).

Values of blood parameters of *S. aegyptiaca* collected during August showed sharp decrease in red blood cells count, haemoglobin content and haematocrit values and improvement in these blood parameters occurred during September (Table 8).

Table 8: Blood parameters of *S. aegyptiaca*.

Variable	*RBCs* (X10^{6}/mm^{3})	*Hb* (g/dl)	*Ht* (%)	*MCV* (μm^{3})	*MCH* (pg/cell)	*MCHC* (%)	*WBCs* (X10^{3}/mm^{3})
June	2.24± 0.11^{A}	6.55 ±0.22^{A}	21.69 ±0.59^{A}	97.50 ±2.58^{C}	29.38± 0.63^{B}	30.17 ±0.42^{A}	83.88 ±4.50^{A}
July	1.41 ±0.08^{B}	4.80 ±0.14^{B}	18.63 ±0.34^{B}	134.74 ±6.33^{A}	34.62 ±1.51^{A}	25.75 ±0.44^{B}	82.75 ±1.50^{A}
August	1.35 ±0.11^{B}	3.70 ±0.24^{C}	14.93 ±0.57^{C}	114.05 ±5.44^{B}	28.05 ±1.82^{B}	24.73 ±1.32^{B}	54.25 ±3.20^{C}
September	2.36 ±0.09^{A}	6.05 ±0.11^{A}	20.45 ±0.65^{A}	87.18 ±2.92^{C}	25.79 ±0.62^{B}	29.69 ±0.58^{A}	63.0 ±1.87^{B}
F-value	29.78*	47.71*	28.38*	20.34*	8.82*	12.41*	23.86*

Different case letters or * indicate significant differences ($P< 0.01$).

Blood glucose level, *AST*, *ALT*, creatinine and uric acid values showed significant increase while values of plasma total lipids were significantly low during August (Table 9).

Data showed a significant decrease in plasma total proteins and globulin together with a significant increase in albumin and A/G ratio of fish collected during August in comparison to the results in other months (Table 10).

There was a decrease in muscle total proteins and total lipids associated with an increase in muscle water content and ash percentage in fish samples collected during August (Table 11).

Table 9: Plasma constituents of *S. aegyptiaca*.

Variable	Glucose (mg/dl)	Total lipids (g/l)	*AST* (u/l)	*ALT* (u/l)	Creatinine (mg/dl)	Uric acid (mg/dl)
June	80.0 ±4.48^{D}	6.65 ±0.18^{A}	29.25 ±1.18^{D}	7.63 ±0.36^{C}	2.38 ±0.05^{C}	22.28± 0.89^{C}
July	113.50 ±3.59^{B}	4.19 ±0.11^{C}	62.0 ±3.74^{B}	18.0 ±0.89^{B}	2.94 ±0.08^{B}	29.48 ± 0.46^{B}
August	125.25 ±1.08^{A}	3.98 ±0.11^{C}	88.0 ±1.38^{A}	32.45 ±2.15^{A}	4.08 ±0.24^{A}	40.85 ±3.38^{A}
September	91.0± 2.19^{C}	5.13 ±0.11^{B}	35.50 ±1.02^{C}	15.63 ±0.83^{B}	2.56 ±0.14$^{B/C}$	33.93 ±2.02^{B}
F-value	43.70*	88.66*	158.0*	68.43*	26.27*	14.69*

Table 10: Plasma protein pattern of *S. aegyptiaca*.

Variable	Total proteins (g/dl)	Albumin (g/dl)	Globulin (g/dl)	A/G ratio
June	5.43 ±0.42^{A}	0.62 ±0.02^{C}	4.81 ±0.40^{A}	0.13 ±0.01^{B}
July	3.45 ±0.04^{C}	0.97 ±0.03^{B}	2.48 ±0.01^{C}	0.39 ±0.01^{B}
August	2.23 ±0.09^{D}	1.66 ±0.15^{A}	0.58 ±0.07^{D}	3.48 ±0.79^{A}
September	4.12 ±0.13^{B}	0.69 ±0.03^{C}	3.43 ±0.12^{B}	0.20 ±0.01^{B}
F-value	35.05*	35.32*	71.01*	16.77*

Table 11: Muscle chemical composition of *S. aegyptiaca*.

Variable	Water content (%)	Total proteins (% wet weight)	Total lipids (% wet weight)	Ash (% wet weight)
June	77.90 ±0.45^{B}	16.42 ±0.35^{A}	3.93 ±0.56$^{A/B}$	1.94 ±0.17$^{A/B}$
July	77.67 ±0.53^{B}	16.26 ±0.59^{A}	3.99 ±0.50^{A}	1.87 ±0.43^{B}
August	79.62± 1.02^{A}	15.03 ±0.98^{B}	2.14 ±0.18^{C}	2.19 ±0.29^{A}
September	77.22 ±1.07^{B}	15.95 ±0.38^{A}	3.51 ±0.38^{B}	1.78 ±0.07^{B}
F-value	13.20*	7.70*	32.30*	3.23*

Different case letters or * indicate significant differences ($P< 0.01$).

Heavy metals pose serious water pollution problem due to their toxicity, persistence and bioaccumulation. Metals that are deposited into the aquatic environment may accumulate in the food chain and cause ecological damage and also pose carcinogenic and other adverse effects on human health due to biomagnifications over time. Aquatic organisms have been reported to accumulate heavy metals in their tissues several times higher than the ambient levels by absorption process through gills or by consumption of contaminated food and sediments (Malik *et al.,* 2010).

Changes in the physicochemical properties of water samples collected from Lake Qaroun during summer and beginning of autumn seasons (Table 1) reflect monthly changes in water quality, disturbances in the aquatic habitat and consequently fish quality. This is in agreement with Abdel-Satar *et al.,* (2010) who studied the seasonal changes in the lake and indicated the deterioration of water parameters and accumulation of heavy metals during summer and autumn seasons depending mainly on the fluctuations of drainage input and the rate of evaporation.

According to Fathi and Flower (2005) the maximum crop density was in August and the influx of water from all the drains reached highest values during late summer. They also postulated that salinity was relatively high in summer (mean= 43.9 g/l) and decreased to minimum levels during winter months (mean= 26.4 g/l). Meanwhile, Abd-Ellah (2009) detected a significant decrease in water level of Lake Qaroun during summer season and this was attributed mainly to the high rate of evaporation. These facts support the present findings. Values of measured water heavy metals are in agreement with Elghobashy *et al.,* (2001) who attributed the increase of heavy metals in drainage water to the decomposition of the organic matter and/or the use of fertilizers and other chemicals in agriculture. Finally, the least levels of all the studied heavy metals were in samples collected during September. These results were confirmed by many investigators (Bishai and Kirollus, 1980; Mansour *et al.,* 2000; Abdel-Satar *et al.,* 2010) who reported that Lake Qaroun showed a gradual increase in salinity and heavy metals during the last century due to its closed nature and extensive evaporation especially during summer. Therefore, salts and heavy metals carried by agricultural drainage water accumulate in the lake components. The distribution pattern of water heavy metals (Cu^{+2}, Zn^{+2}, Mn^{+2} and Pb^{+2}) could be attributed to drain inflow values which reach their maximum during July and the end of summer season (Fathi and Flower, 2005).

Target organs, such as liver, kidneys and gills are metabolically active tissues and accumulate heavy metals at higher levels (Qiao-qiao *et al.,* 2007). Moreover, the uptake of metals by fish involves transfer of metals through gills, intestine or skin to the circulatory system, and then proceeds to the organs of detoxification (liver, spleen and kidneys) either for long-term storage or excretion (Heath, 1987). The detected significant increase of residual heavy metals in fish viscera (including liver and kidneys) more than in the edible muscle tissues is in agreement with previous reports of Khalil and Hussein (1996) and Elghobashy *et al.* (2001). On the other hand, the lowest bioaccumulated heavy metals in muscles may be correlated with fat-content in muscle tissues and its low affinity to combine with heavy metals and/or because of muscle low metabolic activity (Uluturhan and Kucuksezgin, 2007).

Sections of gills, liver and kidneys of *S. aegyptiaca* collected from the lake during June showed much more improvement than samples collected during other months. This may be attributed to the low water heavy metal concentrations (as low agricultural discharge) also due to the better water quality. However, samples collected during late summer and beginning of autumn seasons showed severe histopathological changes which were generally in accordance with the results of residual heavy metals in tissues. Exposure of sole fish to different concentrations of heavy metals caused damage to gill epithelium which consequently facilitated the passage of metals to other fish tissues (Wagh *et al.,* 1985).

There was a progressive damage of kidney tubules associated with tubular necrosis, injury of the wall of renal blood vessels, degeneration of hyaline droplets and swelling of epithelial cells. These signs of necrosis and disintegration of kidney tubules due to heavy metal toxicity are in consistency with Al-Zahaby *et al.* (1998) who described vacuolation and disintegration in kidney tubules of *Sarotherodon galilaeus* exposed to medium levels of Cu^{+2}, Zn^{+2} and Pb^{+2} (1/2 LC_{50}), while those exposed to higher concentrations of these metals showed higher degrees of disintegration. These injuries and damages to tissues suggest too slow defense mechanisms in these cells to immobilize or eliminate ingested heavy metals, demonstrating the sensitivity of fish cells to metals exposure (Mela *et al.,* 2007).

Growth is a sensitive and reliable endpoint in chronic toxicological investigations. One of the growth indices in fish is the condition factor (*CF*) which has been accepted as integrative indicator of general fish condition and can provide information on the ability of animals to tolerate environmental stresses. Therefore, *CF* can be estimated for comparative purposes to assess the impact of environmental alterations on fish performance (Barton *et al.,* 2002) but does not give information of specific responses to toxic substances in the media (Linde-Arias *et al.,* 2008). Therefore, the fluctuation in *CF* values reflects the health condition of fish as well as their body protein and lipid contents (Weatherley and Gill, 1987). The low *CF* values in fish collected during August and July in comparison with that of fish collected during the other two months (Table 7) may reflect the toxic effect of the recorded heavy metals in water or bioaccumulated in fish tissues. This could be as a result of either reduced food intake or increased metabolic expenditure (DeBoeck *et al.,* 1997).

In various fish species, liver weight is positively associated with seasonally fluctuating water and glycogen contents. The relative size of the liver should be correlated with the nutritional status and the growth rate of the fish (Schreck and Moyle, 1990). The *HSI* results may be attributed to the depletion of liver glycogen followed by hyperglycemia reflecting the fish's need for energy necessary to resist the stress as reported by Diwan *et al.* (1979). Values of liver water content (Table 7) could be attributed to the bioaccumulated heavy metals in hepatic tissues which were accompanied by histopathological changes and consequently an inverse dynamic relationship between liver organic constituents and its water content as previously reported by Weatherley and Gill (1987).

Haematological techniques have proven to be valuable for fisheries biologists in assessing environmental health and in monitoring normal or pathological processes in fish (Mercaldo-Allen *et al.,* 2003). The decrease in the studied blood parameters may be attributed to *RBCs* haemolysis indicated by the histological investigations which showed intravascular haemolysis in the blood vessels of the liver and kidneys. It may also be due to reduction in production and output of cells from haemopoietic tissues (Khadre, 1988). Exposure to heavy metals lead to reduced haemoglobin content and haematocrit via disorders in haemopoietic processes and accelerated disintegration of erythrocyte cell membranes (Svobodova *et al.,* 1997).

The recorded significant decrease in *WBCs* of fish samples collected during August and September could be attributed to primary or secondary changes in haemopoietic organs, inhibited maturation of leukocytes and their premature release to blood from tissue reserves or as a stress response to toxic compounds (Srivastava and Sahai, 1987; Brucka-Jastrzebska and Protasowicki, 2005).

The calculated blood indices (*MCV*, *MCH* and *MCHC*) (Table 8) have particular importance in describing anemia in most animals (Coles, 1986). The decrease in some blood parameters (*RBCs* count, *Hb* and *Ht* values) was accompanied by an increase in *MCV* (Macrocytic anemia) as erythrocyte swelling is related to intracellular osmotic disorders and stress (Nikinmaa and Huestis, 1984). The increase in *MCV* is attributed to the direct effect of catecholamines, cortisol, and glucose on adenylate cyclase activities in red blood cells, as a response to acute hypoxic stress (Perry *et al.,* 1996). Moreover, the changes in *MCH* and *MCHC* could be attributed to *RBCs* haemolysis and the reduction of *RBCs* production in the haemopoietic tissues under the action of the bioaccumulated heavy metals. As indicated by Pages *et al.* (1995), the histopathological alterations together with the decrease in amount of oxygen in blood due to gill tissue damage my cause chronic anemia in some cases and consequently severe decline in the haemoglobin, haematocrit and circulating erythrocytes.

Blood glucose appears to be a sensitive and reliable indicator of environmental stress in fish (Nemcsok and Boross, 1982). Environmental pollution may produce stress in fish enhancing glycogen breakdown in liver and consequently raise blood glucose level (Diwan *et al.,* 1979). In the present study, the reported hyperglycemia of studied fish species collected during August may be due to enhanced glycogen breakdown in liver, probably because of the highly toxic heavy metals in water (Diwan *et al.,* 1979) and/or an increase in plasma concentration of catecholamines (Pickering, 1981) and corticosteroids (Mazeaud *et al.,* 1977) as a stress response of fish subjected to environmental alterations. Moreover, the increase in glucose level may be attributed to the accumulation of heavy metals in the pancreatic islets that damage the insulin producing *ß*-cells as reported by Khanna and Gill (1975).

The reported decrease in plasma total lipids of fish collected during August could be attributed to the great demand of energy to confront stress conditions (El-Naggar *et al.,* 1998), or to the increase in secretion of catecholamines (Pickering, 1981) and corticosteroids (Mazeaud *et al.,* 1977) as a result of pollutant stress which enhance the metabolic rate and reduce the metabolic reserve.

Enzymes such as aminotransferases (*AST* and *ALT*) may increase in blood as a result of leakage from cells in injured tissues and hence are used as indicators of specific or multiple organ dysfunctions (Boyd, 1983). The results showed significant increase in the activities of *AST* and *ALT* in plasma of *S. aegyptiaca* collected during August, July and a significant decrease in September. This may be attributed to the damage in liver tissues by the action of the recorded bioaccumulated heavy metals. Moreover, Boyd (1983) suggested that liver is rich in *AST* and *ALT* so any damage could result in liberation of large quantities of these enzymes to the blood.

Plasma creatinine and uric acid can be used as rough indices of the glomerular filtration rate and kidney dysfunction (Maita *et al.,* 1984). Low levels of creatinine and uric acid have no significance but their increase indicates several disturbances in kidneys (Maxine and Benjamin, 1985). The elevation in plasma creatinine and uric acid in fish collected during July and August may be attributed to the action of accumulated heavy metals on renal tubules and consequently caused pathological changes in the kidneys. These results are supported by the findings of Al-Zahaby *et al.* (1998) who illustrated that exposure of fish to high concentration of heavy metals led to disintegration of the renal epithelium, displacement of nuclei, shrinkage of glomeruli, breakdown of Bowman's capsules and heavy infiltration by inflammatory cells.

The significant decrease in plasma total proteins and globulin in fish collected during August in comparison to the other months may be of value for energy production during pollutant toxicity and/or due to other several pathological processes including renal damage and their elimination in urine, decrease in liver protein synthesis, alteration in hepatic blood flow and/or plasma dissolution (Gluth and Hanke, 1985). Measurement of plasma albumin is of considerable diagnostic value in animals as it relates to general nutritional status, the integrity of the vascular system and liver functions. Hypoalbuminemia may result from impaired synthesis, loss through urine or feces, or increased catabolism (Nguyen, 1999).

Acclimation of fish to different environmental factors results in increased metabolic activity correlated with changes in the quality and quantity of certain enzymes involved in energy metabolism and with compensating modifications in the rate of protein synthesis (Wallaert and Bobin, 1994). The significant decrease in muscle total proteins and total lipids of fish samples collected during August may be attributed to the disturbance in the physiological status as well as the disorders recorded in the enzymatic activities by the action of heavy metals that critically influence the growth rate and the quality of fish as previously reported by Hodson *et al.* (1984).

Gluth and Hanke (1984) reported that the hepatic and muscle protein contents tend to increase at the beginning but decrease later on exposure of carp; *Cyprinus carpio* to 10 different pollutants. These differences in tissue total protein and total lipids observed in fish after exposure to toxic substances may be due to different mode of pollutant actions. Moreover, the increase in muscle water content of fish in the present study is in agreement with Weatherley and Gill (1987) who reported that depletion of body constituents (total protein and total lipids) results in tissue hydration as an inverse dynamic relationship between protein as well as lipids and water content in the muscle. Also the increase in muscle ash of fish collected during August may be attributed to the bioaccumulation of heavy metals in fish tissues as already indicated in this study and as previously reported by Haggag *et al.* (1999).

Conclusion:

Lake Qaroun remains a valuable natural and cultural resource despite its deterioration during the 20th century. The development of fish productivity in Lake Qaroun can be achieved by introducing high halotolerant fish species such as *S. aegyptiaca*. This new transplanted species acclimatized perfectly to the lake conditions and this could be attributed to its ability to resist the severe deteriorations in water quality (especially during summer seasons) and this was declared through the improvement in the studied growth indices, physiological status as well as clear significant decrease in the bioaccumulated heavy metals in fish tissues at the beginning of autumn season. So, the present study strongly recommends encouragement of transplantation programs of fish especially *S. aegyptiaca* to improve the yield of its original strain in the lake under these deteriorating conditions. *S. aegyptiaca* is considered as a promising fish species in this regard. Also we recommend sustained monitoring of changes in lake conditions as an assist to formulate wise management policy for Lake Qaroun. Further research work is needed on other native fish species that could be transplanted to the lake to sustain and increase its yield under these conditions.

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