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ORIGINAL ARTICLE

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Impacts of physicochemical and heavy metal parameters on infestation level of the monogeneans, *Quadriacanthus* spp. infesting Nile catfish, *Clarias gariepinus* of different water localities in Nile Delta, Egypt

Mohamed Ibrahim Mashaly[1] · Hend Essam Allam[1] · Mohamed Mohamed El-Naggar[1]

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Abstract Fish parasites can be used as bio-indicators to evaluate pollution degree in aquatic ecosystems. Limited research has, however, investigated the potentiality of these parasitic worms to tolerate various environmental factors. This study, therefore, investigated whether the gill, *Quadriacanthus* monogenean parasites of *Bagrus bajad* Forskål, 1775 are potential bio-indicators of aquatic ecosystem health. The seasonal differences in prevalence, mean intensity and abundance of *Quadriacanthus* species of *Clarias gariepinus* varied between each other and between the three localities. Most *Quadriacanthus* species exhibited their highest prevalence, mean intensity and abundance in Spring and/or Summer and their lowest values in Autumn and/or Winter. The seasonal differences in prevalence were significant for *Q. kearni* and *Q. clariadis* while a significant difference in the mean intensity between different seasons was recorded only for *Q. aegypticus*. Also, seasonal differences in the abundance were highly significant for *Q. aegypticus* and significant for *Q. kearni.* The total dissolved solids, Chlorides, Sulphate, Sodium, Cadmium and Lead were higher at Manzala Lake than standard permissible limits. The pH has significant correlations with the infestation levels of *all Quadriacanthus* spp. Dissolved oxygen showed a highly significant positive correlation with the mean intensity of *Q. clariadis* and a significant positive correlation with the abundance of *Q. clariadis*. Iron was the only heavy metal to record a significant positive relationship with the mean intensity of *Q. kearni*. It is noteworthy that *Quadriacanthus* species were found to have a noticeable ability to resist the effect of hazardous concentrations of many physicochemical and heavy metals parameters. Therefore, it is highly recommended that these monogeneans could be regarded as bio-indicators for water quality.

Keywords *Quadriacanthus* · *Monogenea* · Physicochemical parameters · Heavy metals · Bio-indicators

Introduction

Fishes of the River Nile, Manzala Lake and canals are important economic sources of animal protein for the Egyptian people. Samy-Kamal (2015) reported that fisheries of the River Nile provide 18.8% while Manzala Lake (brackish water) shares about 18% of the total production in the Nile Delta region. The Egyptian catfish, *Clarias gariepinus* Burchell, 1822, is one of the most popular fish kinds dwelling River Nile, lakes and canals. The total production of *C. gariepinus*, from the River Nile only, was about 20.27% of the total Nile catch in Egypt while the same fish contributed 12.47% of the total catch from lakes (Samy-Kamal 2015). The clariid fish *C. gariepinus* can inhabit water sources with different qualities and pervade throughout the year in higher proportion than any other Egyptian fish (FAO 2018). They are less expensive than other fish species of the River Nile and lakes. Most clariid fishes are of economic value with respect to their importance in aquaculture and *C. gariepinus* was considered as prime African example (Mashaly et al. 2019). Previous taxonomical studies have indicated that the Nile catfish *C. gariepinus* harbors at least 3 *Quadriacanthus* spp. on its gills (Mashaly et al. 2019; Beletew et al. 2016; Francová

✉ Mohamed Ibrahim Mashaly
dr.moh_mashaly@mans.edu.eg

[1] Zoology Department, Faculty of Science, Mansoura University, Mansoura, Egypt

et al. 2017). These parasites were reported to cause serious pathogenic effects to the gills (EL-Naggar et al. 2019; Arya and Singh 2015). Aquatic environmental pollution by chemicals (inorganic and organic) was reported by Saeed and Sakr (2008) to act as a major factor that causes serious threat to the survival of aquatic organisms including fish and their parasites. As fish parasites, particularly the monogeneans that are highly sensitive bio-indicators of environmental pollution (El-Naggar et al. 2017a, b), a good deal of attention should be paid to test and evaluate their validity as environmental bio-monitor. According to Sures (2008), accumulation of bio-indicators delivers more accurate evidence on the quality of the habitat than investigations measuring numerical fluctuations in parasite population or community. El-Naggar et al. (2017b) dealt with the monogeneans as tags to assess heavy metal pollution in the Nile Delta. Both digenean and monogenean parasites were found by Blanar et al. (2009) to be characteristic bio-indicators of heavy metal pollutants.

The present study aims to determine values of water physicochemical parameters and heavy metals concentrations monthly at three water localities of Nile Delta; Manzala Lake (brackish water), Nawasa El-Gheit drain (agricultural drainage water) and Demietta branch of the River Nile (freshwater). These data are necessary for understanding the type of water in each locality and subsequently determine which of these localities is more polluted than the others. The infestation levels (prevalence, mean intensity and abundance) of *Quadriacanthus* spp. infesting the catfish *C. gariepinus* are important to be examined monthly and seasonally in each of these localities to determine the impacts of environmental parameters on their levels in each locality and which season is favorable for the growth of these monogeneans. Moreover, the present study may reveal which of these monogeneans can be used as bio-indicator for water pollution.

Materials and methods

Study area and host collection

A total of 445 specimens of the catfish *C. gariepinus* Burchell, 1822 were collected monthly by trammel nets from three water localities of Nile Delta, Dakahlia Governorate, Egypt at the period of March, 2017 to February, 2018. The first locality is Manzala Lake (brackish water), at EL-Nasima village (coordinates: 31° 13′ 42“ N, 32° 0′ 48” E), South of Manzala Lake, 170 km north to Cairo (Fig. 1). The second locality is Nawasa El-Gheit drain (agricultural drainage water) located in southern of Dakahlia Governorate (coordinates: 30° 57′ 51“ N, 31° 19′ 46” E) near Aga city. The third locality is the Demietta branch of the River Nile (freshwater) at Kafr El-Taweila village (coordinates: 31° 7′ 30“ N, 31° 25′ 49” E) near El-Mansoura city, 120 km north to Cairo (Fig. 1).

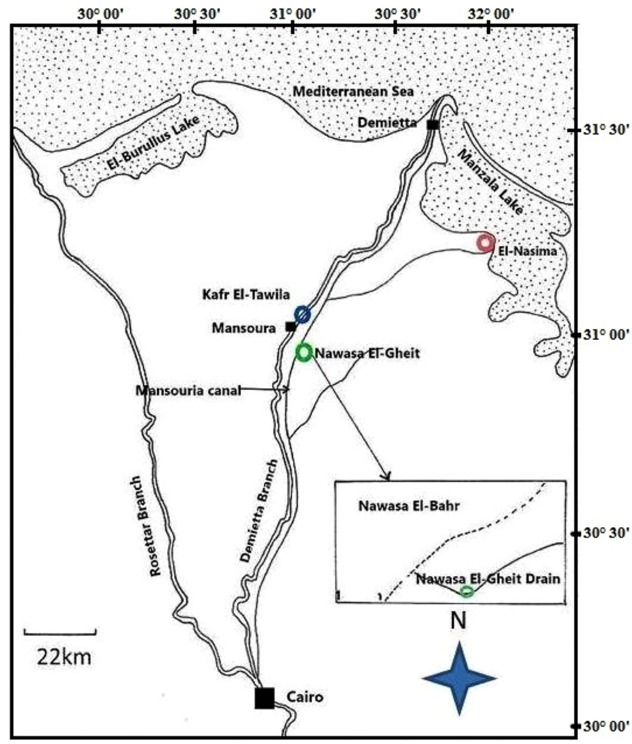

Fig. 1 Map showing the location of investigated sites at Manzala Lake (El Nasima village), Nawasa El-Gheit drain (Nawasa El-Gheit village) and Demietta branch of the River Nile (Kafr El-Taweila village)

Identification of *Quadriacanthus* spp.

Identification of collected *Quadriacanthus* monogenean parasites was done according to Paperna (1961) and El-Naggar and Serag (1985, 1986).

Estimation of physicochemical parameters and heavy metals in the study sites

The following physicochemical parameters were estimated monthly in water samples from each locality: Water temperature (°C), Hydrogen Ion concentration (pH), Electrical Conductivity (EC), dissolved oxygen (DO), Bicarbonates (HCO_3^-), Chlorides (Cl^-), Sulphate (SO_4^{+2}), total dissolved solids (TDS), Sodium (Na^+), Potassium (K^+), Calcium (Ca^{+2}), Magnesium (Mg^{+2}), Nitrogen (N), Phosphorus content (P) and heavy metals including Cadmium (Cd), Lead (Pb), Copper (Cu), Iron (Fe) and Zinc (Zn). Some measurements were carried out in the field and others in the laboratory. The procedures were performed according to Piper (1947), Allen et al. (1974), Olsen and Sommers (1982) and Baird et al. (2012).

Parasitological and statistical analyses

The individuals of each parasitic species were counted for each fish, and during each month. The prevalence (%), mean intensity and abundance were calculated according to Margolis et al. (1982). All data were recorded as Mean ± SD. Pearson Correlation Coefficient was chosen on SPSS package (version 16 for windows) to illustrate the relationship between physicochemical and heavy metal environmental parameters of water and infestation levels of *Quadriacanthus* spp. infesting *C. gariepinus*. The probability levels were selected as follows: non-significant ($p > 0.05$), significant ($p \leq 0.05$), highly significant ($p \leq 0.01$) and very highly significant ($p \leq 0.001$).

One-way ANOVA test using SPSS package (version 16 for Windows) was employed to detect the differences between infestation levels of different monogeneans throughout the year, differences between infestation levels of the monogeneans and different study sites and differences between infestation levels of monogeneans and different seasons. In case of significant differences, the Multiple Range Comparisons (Least Significant Difference) was selected from the PostHoc tests (Tukey HSD) on the same statistical package to detect the variances between infestation levels of different monogeneans, different study sites and different seasons.

Results

Water quality of studied localities

Table 1 shows the monthly fluctuation values of the physical parameters; temperature (°C), Hydrogen ion concentration (pH), Electrical conductivity (EC) and dissolved oxygen (DO) in the three examined sites. Generally, it can be seen that Manzala Lake attained the highest mean values of temperature (24.33 ± 5.28 °C) and EC (2.55 ± 0.75 dS/m) followed by Demietta branch of the River Nile and Nawasa El-Gheit drain while Demietta branch of the River Nile recorded the highest mean value of pH (7.40 ± 0.36) and DO (5.61 ± 0.87 mg/l) followed by Manzala Lake and Nawasa El-Gheit drain.

Concerning the chemical parameters (Tables 2, 3, 4), Manzala Lake attained the highest mean values of Bicarbonate (192.05 ± 98.08 mg/l), Chlorides (447.11 ± 232.99 mg/l), Sulphate (484.18 ± 262 mg/l), total dissolved solids (1653.62 ± 486.47 mg/l), Sodium (519.79 ± 15.15 mg/l), Potassium (6.18 ± 0.66 mg/l), Calcium (46.53 ± 19.79 mg/l) and Magnesium (8.64 ± 5.60 mg/l) followed by Nawasa El-Gheit drain and Demietta Branch of the River Nile. The mean value of Phosphorus showed no variations between the three examined sites while Nitrogen recorded its highest mean value (6.04 ± 1.01 mg/l) at Nawasa El-Gheit drain followed by Manzala Lake and Demietta branch of the River Nile.

Concerning heavy metal concentrations (Table 5), Manzala Lake attained the highest mean values of Cadmium (0.06 ± 0.06 mg/l), Iron (0.17 ± 0.13 mg/l) and Zinc (0.15 ± 0.13 mg/l) followed by Nawasa El-Gheit drain and Demietta branch of the River Nile. However, Copper attained its highest mean value (0.16 ± 0.15 mg/l) at Manzala Lake followed by Demietta branch of the River Nile and Nawasa El-Gheit drain while Lead registered its highest mean value (0.08 ± 0.05 mg/l) at Nawasa El-Gheit drain followed by Demietta Branch of the River Nile and Manzala Lake.

Seasonal fluctuations in the prevalences, mean intensities and abundances of *Quadriacanthus* spp.

Figures 2, 3 and 4 show that all *Quadriacanthus* species attained their highest prevalence at Manzala Lake and Nawasa El-Gheit drain during Spring (varied from 80.43 to 89.13%), except *Q. kearni* during Summer (93.33%) at Nawasa El-Gheit drain. At Demietta branch of the River Nile, all *Quadriacanthus* species recorded their highest prevalence during Winter (54.76% for *Q. clariadis* and 61.90% for *Q. kearni*), except *Q. aegypticus* during Summer (72.72%). All *Quadriacanthus* species showed the lowest prevalence during Autumn at both Nawasa El-Gheit drain and Demietta branch of the River Nile (varied from 16.33 to 63.3%) while at Manzala Lake; they showed their lowest mean prevalence during Summer (varied from 44.12 to 50.00%).

One-way ANOVA test has revealed that the seasonal differences in the prevalence were significant for *Q. kearni* ($F = 3.88$, $p = 0.02$) and *Q. clariadis* ($F = 2.97$, $p = 0.04$) among various seasons. Multiple Range Comparisons revealed a significant difference in the prevalence of *Q. kearni* between Winter and Autumn ($p = 0.01$) higher than between Spring and Autumn ($p = 0.03$).

Concerning mean intensity values, Figs. 5, 6 and 7 show that, at Manzala Lake, all *Quadriacanthus* species attained their highest mean intensity during Winter (varied from 3.57 to 8.28). At Nawasa El-Gheit drain and Demietta branch of the River Nile, *Q. aegypticus* and *Q. kearni* recorded their highest mean intensity during Spring (varied from 3.30 to 8.10) while *Q. clariadis* during Autumn for Nawasa El-Gheit drain (2.60) and during Winter for Demietta branch of the River Nile (2.61).

Table 1 Monthly variations of the physical water parameters of the study sites: Manzala Lake (M), Nawasa El-Gheit drain (N) and Demietta branch of the River Nile (R)

Month	Physical water parameters											
	Temperature (°C)			Hydrogen ion concentration (pH)			Electrical conductivity (EC) (dS/m)			Dissolved oxygen (mg/l)		
	M	N	R	M	N	R	M	N	R	M	N	R
March (2017)	19.00	17.00$^{(-)}$	18.00	6.90	7.30	7.50	0.98	0.39	0.33	6.10	5.80	6.30
April	20.00	19.00	21.00	7.64$^{(+)}$	7.65$^{(+)}$	7.80	2.58	1.25	0.41	4.00$^{(-)}$	5.30	6.10
May	22.00	26.00	23.00	6.98	6.72$^{(-)}$	7.18	1.84	0.88	0.27$^{(-)}$	5.50	4.30	5.20
June	28.00	26.00	28.00	7.25	7.05	7.85	3.14	1.42	0.42$^{(+)}$	6.10	3.10$^{(-)}$	5.50
July	30.00	31.00	33.00$^{(+)}$	7.18	7.22	6.70$^{(-)}$	3.30	1.62$^{(+)}$	0.41	4.00	5.10	5.10
August	31.00$^{(+)}$	32.00$^{(+)}$	27.00	7.32	7.10	7.00	3.32$^{(+)}$	0.83	0.29	3.10	4.30	4.20$^{(-)}$
September	26.00	26.00	27.00	7.30	7.53	7.50	3.30	1.35	0.36	4.10	5.10	4.20$^{(-)}$
October	28.00	27.00	28.00	7.50	7.53	7.59	2.95	1.04	0.30	7.10	7.20	6.20
November	27.00	26.00	26.00	7.30	7.20	7.40	2.44	0.36$^{(-)}$	0.37	6.90	8.10$^{(+)}$	7.10$^{(+)}$
December	28.00	21.00	26.00	6.90	6.80	7.10	1.54$^{(-)}$	1.35	0.42$^{(+)}$	7.10	5.40	6.10
January (2018)	18.00	20.00	17.10	6.70$^{(-)}$	6.90	7.86$^{(+)}$	2.61	1.31	0.42$^{(+)}$	7.20$^{(+)}$	5.30	5.20
February	15.00$^{(-)}$	17.00$^{(-)}$	14.00$^{(-)}$	7.18	7.15	7.32	2.58	1.22	0.31	5.30	4.20	6.10
Mean	24.33	24.01	24.05	7.18	7.18	7.40	2.55	1.09	0.36	5.54	5.27	5.61
± SD	5.28	5.09	5.44	0.27	0.29	0.36	0.75	0.40	0.06	1.44	1.34	0.87

Highest value = (+), Lowest value = (−)

Table 2 Monthly variations of the chemical water variables from the study sites: Manzala Lake (M), Nawasa El-Gheit drain (N) and Demietta branch of the River Nile (R)

Month	Water variables											
	Bicarbonates (HCO_3^-) (mg/l)			Chlorides (Cl^-) (mg/l)			Sulphates (SO_4^{+2}) (mg/l)			Total dissolved solids (DS) (mg/l)		
	M	N	R	M	N	R	M	N	R	M	N	R
March (2017)	27.08$^{(-)}$	27.08$^{(-)}$	13.54$^{(-)}$	33.37$^{(-)}$	33.37$^{(-)}$	26.70	404.93	118.37	111.17$^{(+)}$	628.48$^{(-)}$	246.40	210.56
April	243.76	162.50	81.25	600.66	166.85	50.06$^{(+)}$	234.43$^{(-)}$	246.53	65.18	1651.00	800.00	262.40
May	257.30	203.13$^{(+)}$	67.71	317.02	83.43	16.69	252.10	151.68	53.79	1177.60	565.76	172.80$^{(-)}$
June	203.13	148.96	94.79	700.77	206.89$^{(+)}$	40.04	399.84	284.64	73.34	2009.60	908.80	269.44$^{(+)}$
July	257.30	148.96	67.71	734.14$^{(+)}$	200.22	33.37	388.90	389.66$^{(+)}$	100.32	2112.00	1036.00$^{(+)}$	264.96
August	270.84	135.42	94.79	300.33	80.09	36.71	974.40$^{(+)}$	184.51	14.98$^{(-)}$	2124.80$^{(+)}$	532.48	185.60
September	311.47$^{(+)}$	176.05	108.34	317.02	150.17	40.04	910.27	306.43	32.93	2112.00	864.00	229.76
October	54.17	40.63	27.08	467.18	133.48	16.69	741.70	286.75	100.61	1888.00	665.60	192.64
November	54.17	108.34	121.88$^{(+)}$	400.44	40.04	46.72	587.14	32.93	20.45	1561.00	229.76$^{(-)}$	239.36
December	135.42	135.42	31.20	143.49	150.17	15.42	438.62	338.40	103.65	985.60	864.00	202.51
January (2018)	245.78	160.20	95.78	650.66	171.12	35.10	243.43	231.52	65.18	1851.30	722.00	261.33
February	244.15	87.88	30.08	700.22	45.71	16.69	234.43$^{(-)}$	21.45$^{(-)}$	101.62	1742.10	239.36	182.63
Mean	192.05	127.88	69.51	447.11	121.80	31.19	484.18	216.07	70.27	1653.62	639.51	222.83
± SD	98.08	53.07	36.08	232.99	62.60	12.45	262.84	116.86	34.19	486.47	280.13	36.05

Highest value = (+), lowest value = (−)

One-way ANOVA test showed that seasonal differences in the mean intensity were significant for *Q. aegypticus* (F = 3.88, $p = 0.02$) among various seasons. Multiple Range Comparisons revealed a significant difference

Table 3 Monthly variations of water minerals from the study sites: Manzala Lake (M), Nawasa El-Gheit drain (N) and Demietta branch of the River Nile (R)

Month	Water minerals											
	Sodium (mg/l)			Potassium (mg/l)			Calcium (mg/l)			Magnesium (mg/l)		
	M	N	R	M	N	R	M	N	R	M	N	R
March (2017)	211.58$^{(-)}$	74.57	63.60$^{(+)}$	5.50	5.00$^{(-)}$	5.50	8.80$^{(-)}$	8.80$^{(-)}$	4.40$^{(-)}$	0.48$^{(-)}$	0.48	1.97
April	515.98	236.13	56.03	6.50	6.00	5.00	44.00	22.00	17.60	12.00	11.76	7.87
May	371.68	164.76	36.49	5.00$^{(-)}$	5.50	6.00	35.30	26.40	17.60	4.22	2.59	0.96$^{(-)}$
June	629.76	289.95	62.98	7.00$^{(+)}$	6.00	5.00	44.00	26.40	13.20	19.68$^{(+)}$	1.44	8.21
July	644.78	302.83$^{(+)}$	62.54	6.50	6.00	5.50	79.20$^{(+)}$	30.80	17.60	10.08	16.08$^{(+)}$	4.80
August	663.21$^{(+)}$	155.30	44.77	5.50	5.00$^{(-)}$	6.00	70.40	22.00	8.80	8.45	4.08	4.32
September	645.36	266.64	43.42	5.50	7.00$^{(+)}$	6.50	74.80	26.40	17.60	12.72	4.90	7.87
October	626.54	195.93	36.85	7.00$^{(+)}$	6.00	5.00	35.20	26.40	17.60	3.84	4.90	4.80
November	509.83	49.31$^{(-)}$	24.20$^{(-)}$	6.00	6.50	7.50$^{(+)}$	35.20	17.60	44.00$^{(+)}$	3.84	4.80	3.55
December	288.55	266.64	34.76	6.50	7.00$^{(+)}$	5.50	48.40	26.40	18.30	3.22	4.90	4.71
January (2018)	612.97	246.51	44.21	6.50	5.50	5.00	42.00	21.22	17.61	13.11	10.17	8.13$^{(+)}$
February	516.91	267.64	35.85	6.70	7.00$^{(+)}$	5.00	41.00	46.20$^{(+)}$	17.60	12.00	3.51	4.81
Mean	519.76	209.68	45.48	6.18	6.04	5.63	46.53	25.05	17.66	8.64	5.80	5.17
± SD	152.15	83.21	13.00	0.66	0.72	0.77	19.79	8.75	9.38	5.60	4.57	2.42

Highest value = (+), lowest value = (−)

Table 4 Monthly variations of the Nitrogen and Phosphorus content from the study sites: Manzala Lake (M), Nawasa El-Gheit drain (N) and Demietta branch of the River Nile (R)

Month	Water variable					
	Nitrogen (mg/l)			Phosphorus (mg/l)		
	M	N	R	M	N	R
March (2017)	6.93	7.56	5.67$^{(+)}$	0.10	0.11	0.10
April	4.41	5.67	3.15$^{(-)}$	0.10	0.08$^{(-)}$	0.11
May	9.45$^{(+)}$	8.19$^{(+)}$	5.04	0.10	0.11	0.12$^{(+)}$
June	5.67	4.41$^{(-)}$	5.04	0.11	0.12$^{(+)}$	0.10
July	3.78$^{(-)}$	5.04	3.15$^{(-)}$	0.12$^{(+)}$	0.11	0.09$^{(-)}$
August	6.30	5.67	5.04	0.10	0.10	0.11
September	5.67	6.30	5.67$^{(+)}$	0.11	0.11	0.10
October	5.67	5.67	5.04	0.10	0.10	0.11
November	5.04	5.67	5.67$^{(+)}$	0.11	0.10	0.10
December	5.04	6.30	5.04	0.11	0.11	0.12$^{(+)}$
January (2018)	5.14	6.18	4.97	0.09$^{(-)}$	0.11	0.10
February	6.12	5.87	5.04	0.12$^{(+)}$	0.11	0.12$^{(+)}$
Mean	5.77	6.04	4.88	0.11	0.11	0.11
± SD	1.43	1.01	0.85	0.01	0.01	0.01

Highest value = (+), lowest value = (−)

between Summer and Winter ($p = 0.01$) higher than between Spring and Winter ($p = 0.08$).

It appears from Figs. 8, 9 and 10 that all *Quadriacanthus* species attained their highest abundance in all investigated sites during Spring (varied from 2.05 to 7.48) except *Q. aegypticus* during Winter at Demietta branch of the River Nile (3.38) and also *Q. clariadis* during Winter at both Manzala Lake (3.80) and Nawasa El-Gheit drain (1.43).

One-way ANOVA test revealed that the seasonal differences in the abundance were highly significant for *Q.*

Table 5 Monthly variations in concentration (mg/l) of the heavy metals: Cadmium (Cd), Lead (Pb), Copper (Cu), Iron (Fe) and Zinc (Zn) from the study sites: Manzala Lake (M), Nawasa El-Gheit drain (N) and Demietta branch of the River Nile (R)

Month	Heavy metals														
	Cadmium (Cd) (mg/l)			Lead (Pb) (mg/l)			Copper (Cu) (mg/l)			Iron (Fe) (mg/l)			Zinc (Zn) (mg/l)		
	M	N	R	M	N	R	M	N	R	M	N	R	M	N	R
March (2017)	0.16	0.01$^{(-)}$	0.04	0.09	0.09	0.05	0.08	0.04	0.05	0.26	0.35$^{(+)}$	0.05	0.08	0.06	0.01
April	0.01$^{(-)}$	0.03	0.01$^{(-)}$	0.03$^{(-)}$	0.09	0.01$^{(-)}$	0.57$^{(+)}$	0.05	0.05	0.26	0.04	0.005$^{(-)}$	0.02$^{(-)}$	0.73$^{(+)}$	0.02
May	0.12$^{(+)}$	0.04	0.05	0.06	0.12	0.02	0.25	0.15	0.26$^{(+)}$	0.05	0.26	0.08	0.07	0.03	0.02
June	0.06	0.06	0.09	0.05	0.13	0.08	0.20	0.10	0.25	0.09	0.04	0.11	0.11	0.11	0.10$^{(+)}$
July	0.01	0.09	0.03	0.09	0.14$^{(+)}$	0.06	0.09	0.09	0.08	0.03$^{(-)}$	0.09	0.04	0.49$^{(+)}$	0.13	0.02
August	0.16	0.02	0.04	0.13$^{(+)}$	0.05	0.02	0.12	0.03	0.08	0.41$^{(+)}$	0.01$^{(-)}$	0.10	0.22	0.03	0.05
September	0.03	0.09	0.06	0.06	0.11	0.08	0.11	0.06	0.06	0.11	0.07	0.03	0.21	0.05	0.01
October	0.03	0.10	0.02	0.04	0.07	0.01$^{(-)}$	0.02$^{(-)}$	0.02$^{(-)}$	0.03$^{(-)}$	0.28	0.09	0.06	0.17	0.01$^{(-)}$	0.03
November	0.03	0.11$^{(+)}$	0.02	0.03$^{(-)}$	0.08	0.01	0.03	0.02$^{(-)}$	0.03$^{(-)}$	0.29	0.09	0.05	0.21	0.01$^{(-)}$	0.04
December	0.07	0.09	0.19$^{(+)}$	0.07	0.01$^{(-)}$	0.01$^{(-)}$	0.04	0.12	0.03$^{(-)}$	0.14	0.04	0.09	0.06	0.05	0.02
January (2018)	0.02	0.01	0.01	0.04	0.02	0.04	0.17	0.06	0.10	0.04	0.02	0.20$^{(+)}$	0.09	0.02	0.00$^{(-)}$
February	0.018	0.05	0.01	0.03$^{(-)}$	0.01$^{(-)}$	0.31$^{(+)}$	0.27	0.26$^{(+)}$	0.08	0.03$^{(-)}$	0.17	0.02	0.05	0.01$^{(-)}$	0.04
Mean	0.06	0.06	0.05	0.06	0.08	0.06	0.16	0.08	0.09	0.17	0.11	0.07	0.15	0.11	0.03
± SD	0.06	0.04	0.05	0.03	0.05	0.08	0.15	0.07	0.08	0.13	0.10	0.05	0.13	0.20	0.03

Highest value = (+), lowest value = (−)

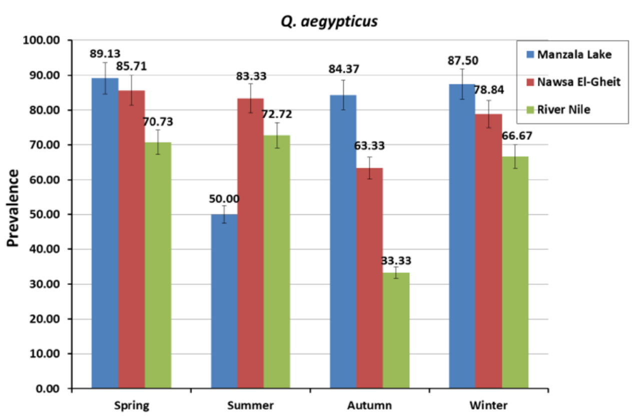

Fig. 2 Seasonal prevalence (%) of *Q. aegypticus*

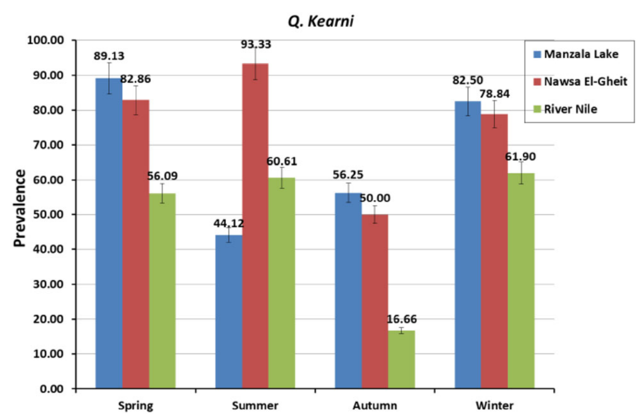

Fig. 3 Seasonal prevalence (%) of *Q. kearni*

aegypticus (F = 5.14, $p = 0.005$), significant for *Q. kearni* (F = 3.85, $p = 0.01$) among various seasons. Multiple Range Comparisons revealed a significant difference between Summer and Winter ($p = 0.003$).

According to relationship between infestation levels in Manzala Lake, Nawasa El-Gheit drain and Demiatta branch of River Nile, One-way ANOVA test demonstrated a very highly significant difference of the prevalence, mean intensity and abundance values between all parasites ($p = 0.000$). Multiple Range Comparisons (PostHoc tests: Tukey) showed a very highly significant difference between infestation levels (prevalence values (%), mean intensity and abundance) of different species ($p = 0.000$).

Correlation between physicochemical and heavy metal environmental parameters and infestation levels of *Quadriacanthus* Spp.

Pearson Correlation Coefficient indicated that, hydrogen ion concentration (pH) has a highly significant negative correlation with the abundance (r = − 0.457, $p = 0.005$) of *Q. aegypticus*, a highly negative significant correlation with the prevalence (r = − 0.486, $p = 0.003$) of *Q.*

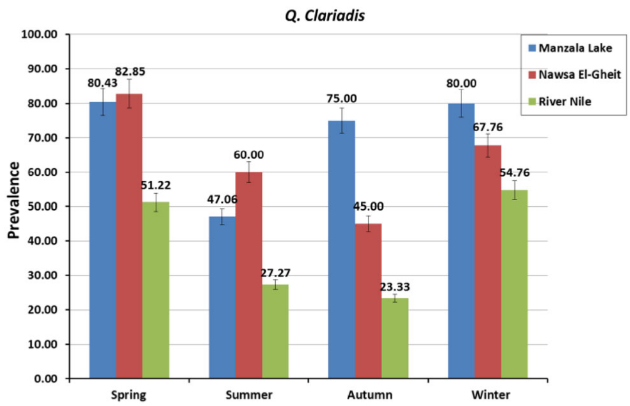

Fig. 4 Seasonal prevalence (%) of *Q. clariadis*

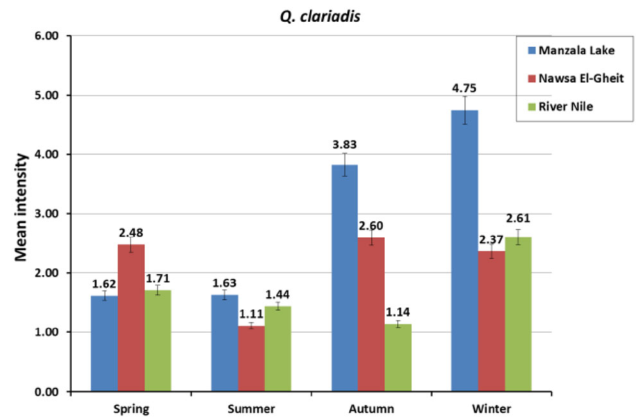

Fig. 7 Seasonal mean intensity of *Q. clariadis*

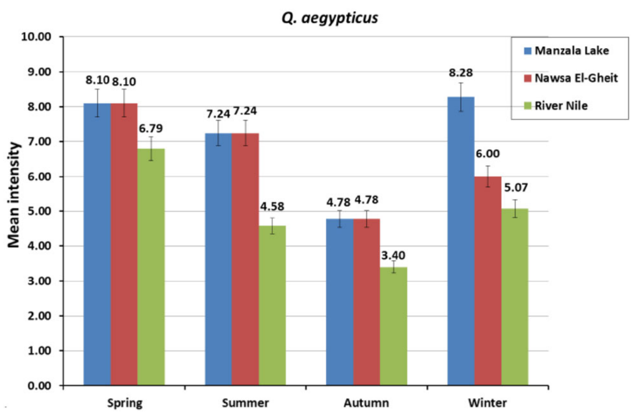

Fig. 5 Seasonal mean intensity of *Q. aegypticus*

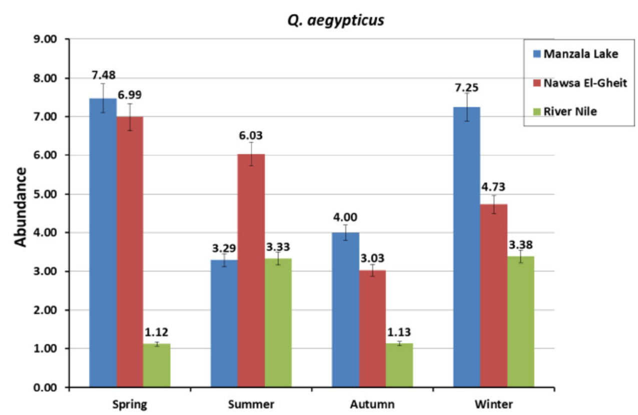

Fig. 8 Seasonal abundance of *Q. aegypticus*

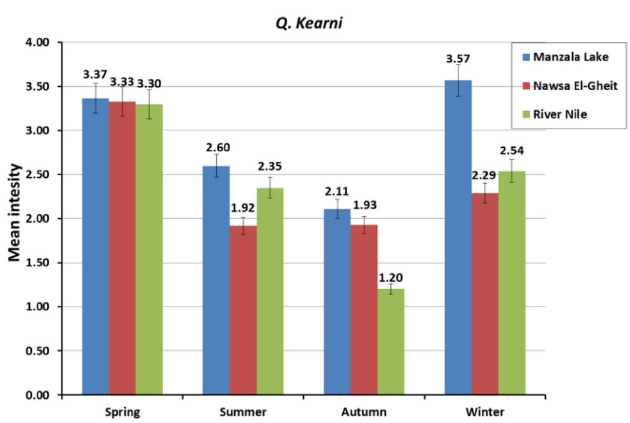

Fig. 6 Seasonal mean intensity of *Q. kearni*

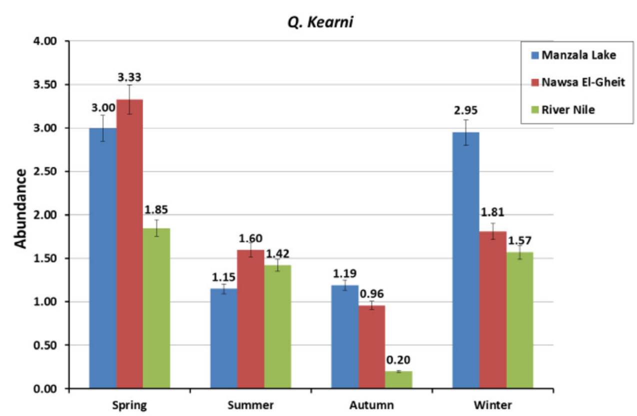

Fig. 9 Seasonal abundance of *Q. kearni*

clariadis, a highly significant negative correlation with the mean intensity (r = − 0.437, p = 0.008) of *Q. aegypticus*, a significant negative correlation with the prevalence (r = − 0.376, p = 0.02) of *Q. aegypticus* and *Q. kearni* (r = − 0.375, p = 0.02) and a significant negative correlation with the abundance (r = − 0.422, p = 0.03) of *Q. clariadis*.

Temperature was found to have a significant negative correlation with the mean intensity (r = − 0.377, p = 0.02) and abundance (r = − 0.348, p = 0.03) of *Q. kearni*. However, dissolved oxygen (DO) was found to have a highly significant positive correlation with the mean intensity (r = 0.436, p = 0.008) of *Q. clariadis*, a

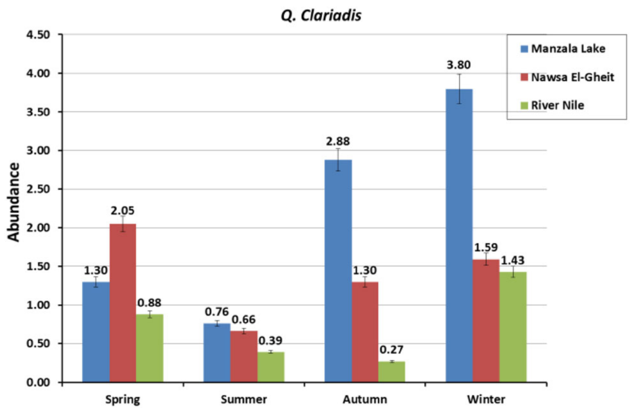

Fig. 10 Seasonal abundance of *Q. clariadis*

significant positive correlation with the abundance (r = 0.422, *p* = 0.01) of *Q. clariadis*. Pearson Correlation Coefficient showed that, Nitrogen (N) has a significant positive correlation with the prevalence (r = 0.328, *p* = 0.05) of *Q. clariadis*, high significant negative correlation with the prevalence (r = – 0.441, *p* = 0.007). Sodium (Na) was found to have a significant positive relationship with the mean prevalence (r = 0.346, *p* = 0.04) of *Q. clariadis*.

Pearson Correlation Coefficient showed that Iron (Fe) was the only heavy metal to have a significant positive relationship with the mean intensity (r = 0.368, *p* = 0.02) of *Q. kearni*. Other heavy metals showed non-significant correlation.

Discussion

The present investigation has revealed that the seasonal differences in the prevalence, mean intensity and abundance of *Quadriacanthus* species of the Nile catfish *C. gariepinus* varied between each other and between the three localities under investigation. According to classification proposed by Valtonen et al. (1997), all *Quadriacanthus* species at both Manzala lake and Nawasa El-Gheit drain were considered as core species (prevalence > 50%). At Demietta branch of the River Nile, *Q. aegypticus* and *Q. kearni* were classified as a core species (prevalence value > 50%) while *Q. clariadis* was considered as (secondary) subdominant species (10–50%). The monogenean parasites have previously been shown to exhibit significant seasonal variations in their prevalence, mean intensity and abundance. Hu and Li (2016) reported that the peak periods represented by high infestation levels are the most harmful periods for the host fish and studying their seasonal dynamics is of great importance for determining the intervention measures required to reduce severe losses particularly in farming conditions.

With few exceptions, most *Quadriacanthus* species of *C. gariepinus* exhibited their highest prevalence, mean intensity and abundance in Spring and/or Summer and their lowest values in Autumn and/or Winter. Statistical analysis showed that the seasonal differences in the prevalence were significant for *Q. kearni* and *Q. clariadis* while a significant difference in the mean intensity between different seasons was recorded only for *Q. aegypticus*. Also, seasonal differences in the abundance were highly significant for *Q. aegypticus* and significant for *Q. kearni*. Similar findings were reported by Hagras et al. (2000) for cichlidogyrid monogeneans of *Oreochromis niloticus* and *Tilapia zilli*. They attributed the low infestation levels during cold seasons to a decrease in the reproductive activity (egg production, hatching and survival of oncomiracidium) of these parasites. In contrast, the population growth of these parasites during hot seasons was attributed to the growing of their biological activities during this period (Hagras et al. 2000). Therefore, it seems likely that temperature plays a significant role in controlling the infestation levels of these parasites. Hu and Li (2016) studied the seasonal population dynamics of the monogenean *Quadriacanthus kobinensis* infesting *Clarias fuscus* in Pearl River, China and found that the prevalence and abundance of this parasite was high in Summer while the mean intensity was high in Autumn. This is nearly consistent with the present observation in that most of the investigated monogeneans showed higher infestation levels in Spring and others in Summer but few in cold seasons (Autumn and Winter). In addition, *Quadriacanthus* species showed wide geographical record as *Q. bagrae* Paperna, 1979 and *Q. clariadis* Paperna, 1961 are recorded in *C. gariepinus*, from the River Gomti, India (Tripathi et al. 2007).

The monogenean parasites are one of the most important sensitive parasites to changes in water physicochemical and heavy metals parameters and therefore, can be used as bio-indicators for monitoring and determining the ecosystem health (Bayoumy et al. 2015; Biswas and Pramanik 2016) Some physicochemical parameters like total dissolved solids, Chlorides, Sulphate and Sodium are higher at Manzala Lake than standard permissible limits determined by WHO (2011). Also, values of some heavy metals like Cadmium and Lead are higher at the three localities than permissible limits. High values of these parameters at Manzala Lake site could be attributed to three types of water received by the lake: sea water from the Mediterranean Sea, drainage water carrying untreated industrial, domestic and agricultural wastes from minor and major drains like Bahr El-Bager, Hadous, Ramsis, Faraskor and El-Serw) and enriched water from Demietta Branch of the River Nile (Ismail and Hettiarachchi 2017). Nawsa El-

Gheit drain receives agricultural drainage water which contains organic fertilizers that increases the pollution in this drain. This is a good indication that water at Manzala Lake is more polluted if compared with that of Nawasa El-Gheit drain and Demietta branch of the River Nile.

In the present investigation, statistical analysis indicated that the pH has significant correlations with the infestation levels of *Q. aegypticus*, *Q. clariadis* and *Q. kearni*. El-Naggar et al. (2017b), working on the monogenean parasites of the same host *C. gariepinus*, suggested no relationship between the monogenean infestation level and pH values of water. However, a positive correlation of pH values and monogenean infestation levels was reported by Barker and Cone (2000) for the monogenean *Pseudodactylogyrus anguilla* infesting *Anguilla rostrata* and by Eissa et al. (2011) for the monogenean parasites of *Tilapia* fish.

Water dissolved oxygen (DO) is regarded as a vital element to the survival of aquatic fauna and subsequently a good indicator of the environmental health. In the present investigation, Demietta branch of the River Nile recorded the highest mean value of dissolved oxygen (DO) and the lowest was attained by Nawasa El-Gheit drain. Dissolved oxygen (DO) showed a highly significant positive correlation with the mean intensity of *Q. clariadis* and a significant positive correlation with the abundance of *Q. clariadis*. Dayoub and Salman (2015) found that the highest monogenean infestation rate was at high temperature, low dissolved oxygen and higher biological oxygen demand.

According to heavy metals values, Manzala Lake attained the highest mean values of Cadmium, Iron and Zinc followed by Nawasa El-Gheit. However, Copper attained its highest mean value at Manzala Lake followed by Demietta branch of the River Nile while Lead registered its highest mean value at Nawasa El-Gheit drain followed by Demietta Branch of the River Nile. Concentrations of Cadmium and Lead were above the permissible limits of WHO (2017). Statistically, Iron was the only heavy metal to record a significant positive relationship with the mean intensity of *Q. kearni*. El-Naggar et al. (2017b) reported that some heavy metals such as Iron, Zinc and Lead appear to have negative impacts on the number of monogenean worms. Cadmium and Copper were reported by Magouz et al. (1996) to induce alterations in the structure of cell chromosomes. Therefore, it seems likely that the presence of heavy metals in higher concentration at Manzala Lake may create a serious effect on the health condition of the catfish *C. gariepinus*. It is noteworthy that *Quadriacanthus* species were found to have a noticeable ability to resist the effect of hazardous concentrations of many physicochemical and heavy metals parameters at Manzala Lake and Nawasa El-Gheit drain. Therefore, it is highly recommended that these monogeneans could be regarded as bio-indicators for water quality of the studied localities.

Conclusion

- According to the dominance value, *Quadriacanthus aegypticus* was the most eudominant species followed by *Q. kearni* and *Q. clariadis*.
- The total dissolved solids, Chlorides, Sulphate, Sodium, Cadmium and Lead were higher at Manzala Lake than standard permissible limits.
- It was evident that pH value, water temperature, dissolved oxygen, nitrogen, sodium and iron showed significant correlations with the infestation levels of *Quadriacanthus* spp.
- The results of this study and similar studies can be used to identify the significant environmental parameters affecting the infestation levels of parasites in order to find solutions to decrease parasites and thus increase the productivity in fish farms and aquaculture.
- Parasites can be considered as suitable tools to investigate host ecology, where the close relationships between the parasitic organisms and their hosts may lead to use of *Quadriacanthus* spp. as biological indicators for environmental pollution.
- Strict control enforced by laws regulation should be applied over polluted industrial wastewater, agricultural drainage water and sewage water debouches into the River Nile and Manzala Lake. All these sources of water input affect the physicochemical characteristics of water, sediments, biological components, fish production and human health.

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Author contributions All authors have participated in conception and design, or analysis and interpretation of the project; drafting the article or revising it critically for important intellectual content; and approval of the final version.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest (financial, academic, commercial, political or personal).

Ethical approval This study was approved by Ethical Committee for Medical Research (MREC) at the National Research Centre (NRC), Egypt and in accordance with local laws and regulations.

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