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Assessment of the Impact of Zebra Mussels on the Ecosystem of the Tigris River

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Abstract

10 sites were selected for investigating zebra mussels in the Tigris River for the study that was conducted for the period from January to December 2020. The results of this investigation showed that zebra mussels were recorded in the Tigris at Taji on sites 7, 8, 9 and 10, while it was not found in the Tigris at Kut on sites 1, 2, 3, 4, 5 and 6. This is the first time that this species was ever recorded in the Tigris. It was found that the sites where zebra mussels appeared had a clear impact on the decrease in the total organic carbon %age and turbidity (NTU). High dissolved oxygen values were observed in the sites where zebra mussels were recorded, and the appearance of zebra mussels in these sites caused a clear decrease in the appearance and total density of benthic invertebrates, in addition to a clear increase in the total density of epiphytic algae. Zebra mussels caused the disappearance of the local species of the phylum Mollusca and crustaceans in the sites where it appeared.

Keywords: Invasive species, *Dreissena polymorpha*, Zebra mussels, Tigris River

تقييم تأثير المحار المخطط Zebra Mussels على النظام البيئي لنهر دجلة

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الخلاصة

سعت الدراسة الى التحري عن تواجد المحار المخطط في نهر دجلة للفترة من كانون الثاني الى كانون الاول 2020 في 10 مواقع ، اظهرت النتائج الدراسة الحالية تسجيل المحار المخطط zebra mussels في نهر دجلة في مدينة التاجي في المواقع 7، 8، 9 و 10 ، بينما لم يتم العثور عليها في نهر دجلة بمدينة الكوت في المواقع 1، 2،3، 4، 5 و 6. يعد هذا أول تسجيل لهذا النوع في نهر دجلة ، بينت نتائج الدراسة الحالية ان لتواجد المحار المخطط تاثير واضح على بعض الخصائص البيئة اذ تسببت في انخفاض في الكربون العضوي (٪) والعكارة، ولوحظ ارتفاع قيم الأكسجين المذاب في المواقع التي تواجد فيها ، كما و كان له تاثير واضح في تغيير مجتمع الاحياء القاعية اذ تسبب في انخفاض الكثافة الكلية للافقاريات القاعية ، و زيادة واضحة في الكثافة الكلية للطحالب الملتصقة على النباتات ، كما وتسبب في اختفاء الأنواع المحلية من شعبة النواعم والقشريات في المواقع التي ظهرت فيها.

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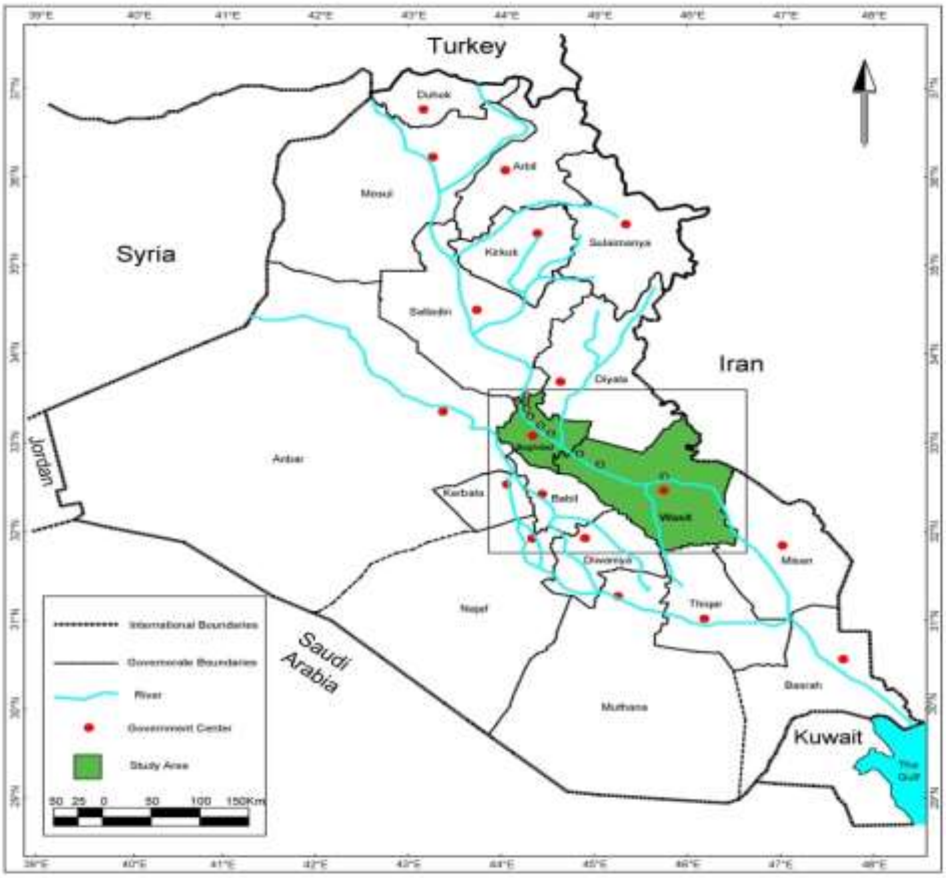
1. Introduction

The presence of invasive species in aquatic environments has a direct impact on the structure of benthic communities, via their influence on native species through the mechanisms of predation and competition. Invasive species also exert indirect effects by changing the physical and biological characteristics of the habitat. Zebra mussels of the species *Dreissena polymorpha* is one of the most importaant invasive species of Mollusca found in freshwater environment [1]. An earlier work indicated that the entry of this species into the Euphrates River occurred during the construction of Keban and Tabqa dams in Turkey [2]. Zebra mussels are also capable of altering food web dynamics in aquatic ecosystems, since they consume the base of the food chain, i.e., zooplankton and plants that are removed from the water column and get redistribute as energy sources to benthic animals [3] [4]. Zhang *et al.* [5] indicated that this species leads to an increase in the growth of these plants due to an increase in water transparency. As far as the economic aspect is concerned, zebra mussels affect industrial establishments as they colonize in water supply pipes in water treatment and power plants. Bobat *et al.* [6] indicated that zebra mussels cause economic damages to dams and hydroelectric power stations built on the Euphrates River in Turkey. Ludyanskiy [7] revealed that the cost of removing and scraping these animals from the openings of water inlet pipes in a power plant in the United States is about 50-100 million USD annually. Zebra mussels were reported to be the biggest cause of biofouling. The adhesion of large numbers of individual animals also causes damages to the foundations of loading docks of ports and fishing gear if left in the water for a long time. Continuous adhesion can cause steel to rust, affecting the integrity of concrete structures [8]. In addition to zebra mussel members role in the food web and their ability to accumulate heavy elements in their bodies and shells, they play a positive role in reducing pollution in water bodies. They can also be used as an effective bioindicator for the concentration of elements in fresh water [3]. Therefore, the study aimed to investigate the spread and establishment of *D. polymorpha* in the Tigris River and its effects on benthic invertebrates and water quality, as it was recorded for the first time in the study sites. This study provided a source as a database for the presence and impact of zebra mussels.

2. Material Methods:

The Tigris River was chosen as a site for the current study to investigate zebra mussels for the period from January to December 2020. 10 sites on the Tigris River were selected (Figure 1): sites 1, 2 and 3 in the city of Kut. and in the city of Baghdad at site 1, site 4 Tigris River - Jadriya and site 5 Tigris River - near the Sarafiya bridge, and sites 7, 8, 9 and 10 on Tigris River in Taji area. Physical and chemical properties were measured at the study sites. These included: water temperature that was measured using a thermometer, pH, Turbidity NTU and salinity were measure using a field conductivity meter. Salinity was calculated according to what is stated in [9] and the total hardness was measured using the method described in [10]. Total Organic Carbon TOC %age was calculated according to what is stated in [11] . For the purpose of studying the rate of settling of the zebra mussels, a number of concrete slabs with an area of square meter were laid at different depths to follow up the settling and growth of zebra mussels monthly, as the number of adherent individuals was calculated. The anchored zebra mussels (Figure 2) were collected from different natural substrates, including stones and rocks on the river's edges, and from submerged aquatic plants. Constancy index (S): calculated the presence and frequency of each species following the formula found in [12]. (C) constant species more than 50%, (Ac) accessory species 26%-50%, (A) accidental species 1-25%. Parameters selected and procedures followed for analysis have been briefly described in Table 1. Less significant difference (LSD) was used to determine the differences between environmental factors means at a significance of ($P \leq 0.05$). All statistics were carried out using

Statistical Analysis System (SAS) software [13]. As for the study of benthic invertebrates, Dredge Eckman was used and a hand shovel of dimensions 15 x 15 cm to collect bottom sediment and aquatic plants. The samples were preserved by adding 4% formalin in a special bottle for laboratory examination. The benthic invertebrates were diagnosed based on the taxonomic keys [14] , [15].



Distance From – To	Distance in Kilometer
S1 – S2	**83.5 Km**
S2 – S3	**28.5 Km**
S3 – S4	**48.0 Km**
S4 – S5	**10.1 Km**
S5 – S6	**6.50 Km**
S6 – S7	**2.70 Km**
S7 – S8	**0.15 Km**
S8 – S9	**0.30 Km**
S9 – S10	**0.15 Km**

Site	Governorate	Coordinates	
		North	South
S1	Wasit	"56.54'29°32	"14.48'49°45
S2	Wasit	"1.05'54°32	"4.41'4°45
S3	Wasit	"51.96'59°32	"56.32'46°44
S4	Baghdad	"51.28'15°33	"31.37'22°44
S5	Baghdad	"11.50'21°33	"26.94'22°44
S6	Baghdad	"13.31'24°33	"21.16'20°44
S7	Baghdad	"39.71'25°33	"47.02'20°44
S8	Baghdad	"44.11'25°33	"48.25'20°44
S9	Baghdad	"40.39'25°33	"38.43'20°44
S10	Baghdad	"44.17'25°33	"37.82'20°44

Figure 1: Iraq map showing the study sites on Tigris River. Map Scale 1/10000.

3. Results and Discussion

The results of the present investigation demonstrated that zebra mussels were recorded in sites 7, 8, 9 and 10, whereas they were not present in sites 1, 2, 3, 4, 5 and 6 (Table 2). This was the first ever recording for this species in the Tigris River. The physical, chemical and biological characteristics of the sites on the Tigris River covered by the current study, were found to have clear effects on some water properties and on the presence and density of the studied species. The results demonstrated significant differences in the values of sediment total organic carbon %age and turbidity (NTU) (Table 1). Decreased values were clearly observed in the sites where zebra mussels appeared (7, 8, 9 and 10). The lowest value of sediment total organic carbon was recorded at site 10, reaching 0.21 %, while the highest value of 0.91% was recorded at site 5 where zebra mussels were not found. As for the turbidity values, they also decreased in the sites where zebra mussels appeared, with the lowest value (14.24 NTU) being recorded in site 8, while the highest values were observed in the sites where zebra mussels did not appear, reaching 32.99 NTU in site 4. Significant differences were also recorded in dissolved oxygen level which increased in the sites where zebra mussels were present, reaching the highest value (11.8) in site 10. While the lowest value (8.8) was recorded in site 3. However, the study showed no significant spatial differences between the water temperature of the sites studied during the same month of the measuring which may be due to the convergent in sampling time, the geographical area and the weather. While the study recorded no significant difference between the sites where the changes in pH values were few and within a tight range, which could be due to the fact that water flows on lands with limestone nature and the presence of carbonate, bicarbonates and silicates ions act as as a buffer nd maintain pH values. The study showed a little variation in total hardness values that were recorded. Hence, the statistical analysis showed no significant spatial differences between the study sites during the period of the study which could possibly due to the total hardness depending on the nature of the rock and soil through which the water passes [10].

These results were expected because all of these sites were located on the Tigris River and hence were influenced by similar conditions. It also turned out that zebra mussels contributed to the transparency of the water as they were able to filter large amounts of water, reaching one litre per day, which led to an increase and a decrease in chlorophyll concentration [16].

Table 1: Average of physico-chemical characteristics of the Tigris River during the study period

Properties	ST1	ST2	ST3	ST4	ST5	ST6	ST7	ST8	ST9	ST10	LSD
Water Temp. C°	8-30	9-29	9-30	8-29	8-28	9-30	9-29	8.5-29	9-29	9-29	**2.87 NS**
pH	7.1-7.7	7-7.3	7-7.5	7.4-7.5	7.4-7.6	7.2-7.6	7.3-7.8	7.4-7.9	7.1-7.6	7.4-7.7	**0.469 NS**
Total Hardness mg $CaCO_3.L^{-1}$	233-260	250-300	300-320	300-330	323-400	230-360	300-320	340-380	320-390	330-389	**69.36 NS**
Salinity $gm.L^{-1}$	0.3-0.5	0.4-0.6	0. 2-0.5	0.5-0.6	0.4-0.5	0. 2-0.5	0.3-0.4	0.4-0.6	0.3-0.5	0.4-0.5	**0.217 NS**
Dissolved oxygen $mg.L^{-1}$	9.5-10	8.9-9.4	8.8-9.4	9.0-9.4	8.9-9.5	9.1-9.8	10.5-11.5	10.9-11.6	11.0-11.4	10.9-11.8	**3.279 ***
Total organic Carbon sediment %	0.5-0.66	0.5-0.70	0.43-0.8	0.5-0.95	0.52-0.91	0.55-0.48	0.33-0.38	0.26-0.36	0.22-0.35	0.21-0.39	**0.672 ***
Turbidity NTU	6.22-47.26	5.93-32.77	5.12-16.19	3.55-32.99	4.24-29.24	7.24-30	3.24-20.24	3.33-14.24	2.89-15.44	3.20-17.30	**6.70 ***

* ($P \leq 0.05$), NS: Not significant.

The prevalence of zebra mussels and their impact on the aquatic communities were also investigated. Temporally (Figure 3), the highest total density of zebra mussels was recorded during the months of November and December 2020, reaching 3000 ind / m² during the month of December at site 7.

Figure 2: *Dreissena polymorpha* stuck to the pedestals.

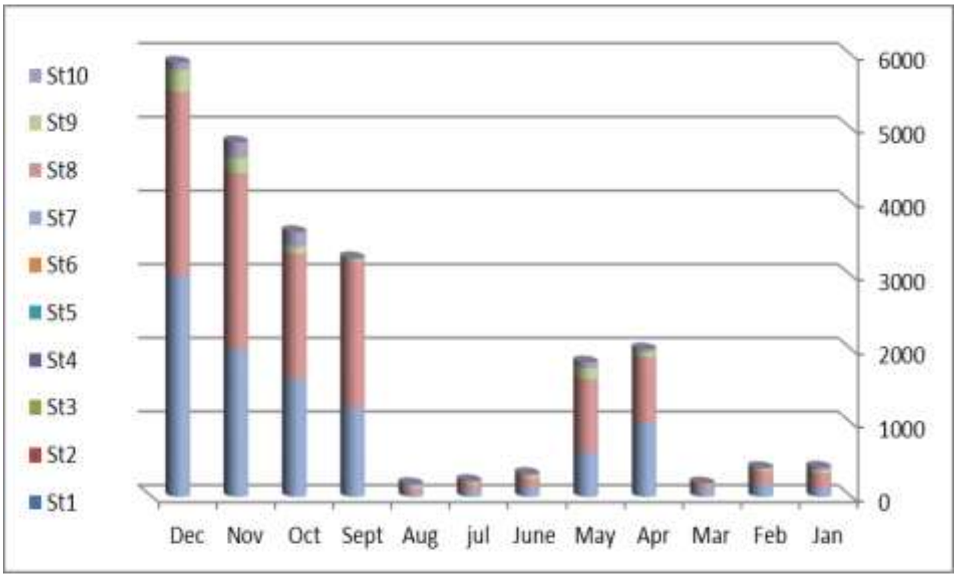


Figure 3: Monthly variations in total density of zebra mussels at the sites during the study period.

However, spatially, the highest total density was recorded at site 8 during the entire months of the study (Table 2), reaching 11243 ind / m². Whereas the lowest total density (792 ind / m²) was recorded at site 10. Our results suggest that zebra mussels showed a preference for sites where foundation bases were available. The highest numbers were recorded in sites 7 and 8 which are sites of fish caging farms where the lack of water movement could have aided to an increase in their number. Also, the presence of zebra mussels in these sites might be attributed to the transport of these fish from environment where zebra mussels were present, which ultimately led to their transfer to the stream of Tigris River.This feature is conferred as the species has a larval stage that is able to spread over long distances, as well as its ability to reproduce at an early age and produce very large numbers of reproductive cells that may reach a million eggs in the full reproductive season. In addition, the species has a high ability to stick to navigation boats in those waters by means of byssal threads, which leads to gatherings that increase the chance of fertilization [17]. This species also has the ability to survive outside water for several days [18]. It was clear that the presence of zebra mussels significantly affected the abundance of other species in the sites in which they appeared for the first time. The presence of invasive species in aquatic environments has direct impacts on the structure of benthic communities, via their influences on native species through the mechanisms of predation and competition. Invasive species also exerted indirect effects by changing the physical and biological characteristics of the habitat [1].

Total 2: Densities of benthic invertebrates during the study period in the sites in the Tigris River.

LSD value	St10	St9	St8	St7	St6	St5	St4	St3	St2	St1	Taxa
149.35 *	720	1122	2133	728	213	430	213	320	336	332	**Epiphytic algae**
271.66 *	11	35	80	119	1029	1054	1373	1279	1070	1204	**Protozoa**
20.38 NS	6	4	6	13	9	15	13	9	22	11	**Hydra**
98.42 *	15	14	14	17	179	242	402	411	689	443	**Rotifera**
82.39 *	24	20	22	22	435	344	483	312	507	199	**Nematoda**
107.16 *	19	20	20	21	176	419	471	518	358	357	**Turbellaria**
163.94 *	40	45	58	59	861	938	999	967	908	952	**Annelida**
132.50 *	19	19	19	19	384	841	685	451	723	777	**Cladocear**
91.77 *	26	32	27	24	279	66	83	71	121	88	**Copepoda**
118.62 *	8	8	8	8	150	309	150	22	265	294	**Amphipoda**
125.47 *	0	0	0	0	64	10	12	19	31	440	**Decapoda**
79.33 *	0	0	0	0	60	274	162	95	211	188	**Ostracoda**
102.59 *	29	29	32	29	838	938	1064	1042	981	755	**Insecta**
98.61 *	0	0	0	0	163	412	179	585	238	407	**Bivalava**
109.36 *	12	13	19	16	274	980	442	991	351	752	**Gastropoda**
148.04 *	792	1017	11243	10040	0	0	0	0	0	0	*Dreissena polymorpha*
---	101.7 *	126.4 *	106.7 *	97.3 *	138.4 *	143.9 *	176.3 *	161.9 *	155.7 *	108.1 *	**LSD value**

The results indicated that the presence of zebra mussels had a significant impact on the relative density of benthic organisms. Epiphytic algae recorded the highest density of 2133 at site 8. According to the constancy index, Epiphytic algae were considered to be a constant species (Figure 2). Nevertheless, the presence of zebra mussels had clear influence on the total densities of the other studied groups as the values were clearly reduced. The protozoans (ciliates, sarcodina and flagella) recorded the highest density at site 7, reaching 119 (Table 2) and have been considered to be among the accidental species.

As for the other groups, the total densities were low and the species were considered as accidental or accessory species, while the local species of bivalvia, decapoda, and ostracoda had disappeared. Figure 4 demonstrates the percentages of the benthic groups in the sites where zebra mussels Total (2) densities benthic invertebrates during the study period in the sites in the Tigris River mussels were present. The appearance of zebra mussels in these sites led to a clear decrease in benthic invertebrates numbers along with a clear increase in the numbers of epiphytic algae. The epiphytic algae showed the highest percentage of 68% of the total studied groups (Figure 4), while protozoa composed 11%. However, the percentages of the remaining groups decreased clearly. Annelida had a value of 5%, while that of 2% was recorded for each of the populations of nematoda, turbelaria, copepoda and rotifera. In addition, gastropoda and hydra groups had a similar percentage of 1%. Suspended particles composed of phytoplankton, large bacteria, detrital material and heterotrophic animals (e.g., zooplankton) as well as nutrients associated with these particles serve as a potential food for zebra mussels.Hence, *D. polymorpha* have affected both pelagic and benthic freshwater communities through feeding on these materials. *D. polymorpha* invasion of most freshwater ecosystems has resulted in a reduction in plankton and benthic biomass, a change in phytoplankton species composition, an increase in water clarity leading to a subsequent increase in macrophyte and periphyton abundance, and an alteration of energy flow from the pelagic to the benthic region. *D. polymorpha* have also been shown to eradicate native bivalves and change nutrients dynamics, alter invertebrates abundance and community structure, and change fish population dynamics [19] , [20] , [21]. Hence, zebra mussel population size is one of the important key factors.

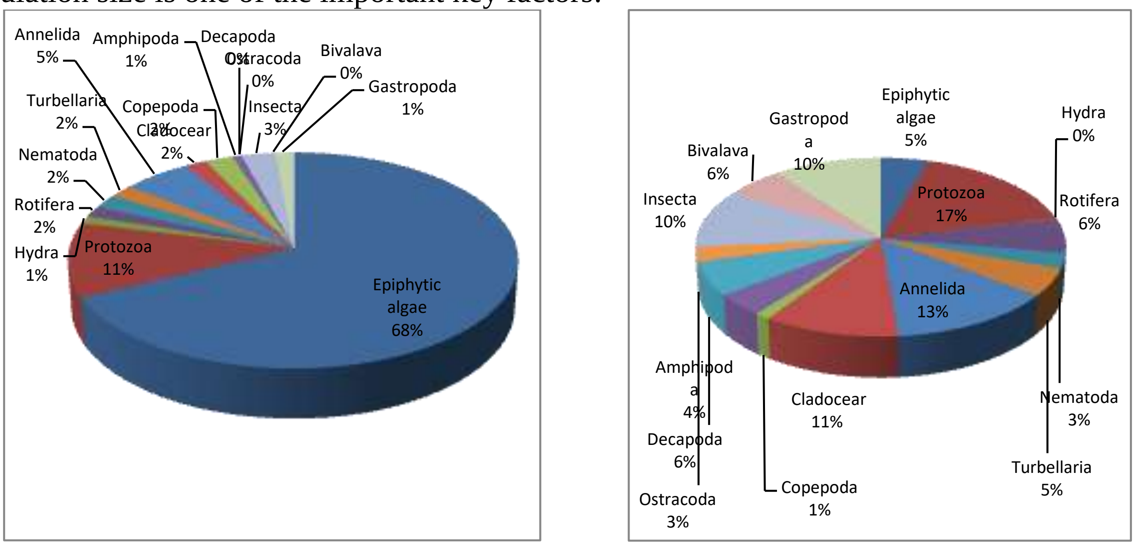


Figure 4: The percentage of benthic invertebrates diagnosed during the study period in the sites in the Tigris River (A- Unappearance, B-Appearance of *Dreissena polymorpha*).

Nevertheless, in the sites where zebra mussels were not recorded, the studied groups showed a clear superiority in their total densities, while the density of Epiphytic algae decreased. Clearly, these results were the opposite of those observed in the presence of oysters (Table 2). The highest density was recorded for the protozoa group (1373), while that for the epiphytic algae was 1844 x 10^3 individuals /gm. The studied groups were considered as constant species in the environment, except for the cladocera, amphipoda, and ostracoda groups, which were considered as accidental species. This is due to their life cycle that is characterized by emergence at moderate temperatures and disappearance in the hot months of the year. The percentages of the groups were as follows (Figure 2): Epiphytic algae showed a very low proportion of 5 % compared to those recorded in the sites where the oyster appeared, while the highest proportion was found for the protozoa group (17 %), followed by the annelida group (13 %). In addition, equal values were recorded for insects, cladocera, and gastropoda (10%), while that for the bivalvia group was 6%. Clearly, in the sites 1-6 where zebra mussels did not appear, the abundance and distribution patterns of species were closely similar. No disappearance or superiority of one group over another was recorded, as happened in sites 7, 8, 9 and 10 where zebra mussels were present. This could be due to the possibility that zebra mussels provided a suitable environment for the dominance of epiphytic algae and the disappearance of groups of benthic invertebrates, especially the local species of bivalvia and crustacea. Based on these findings, it is clear that zebra mussels presence has remarkable effects on several water properties. This species caused a decrease in the numbers of oxygen-producing benthic invertebrates, causing an increase in the percentage of dissolved oxygen, which resulted in the lack of organisms that consume oxygen. Regarding turbidity, its decreased values in the sites where zebra mussels appeared may be due to the nature of the filtration-based feeding behaviour of zebra mussels, which functions through filtering water of suspended particles. Zebra mussels also contributed to a decrease in the proportion of total organic carbon in the sediment. The role of zebra mussels is not limited to being an invasive species only, but also involves controlling the invaded water bodies [3]. The species is also considered as an effective contributor to ecosystem engineering. It was indicated that zebra mussels change both the structure and function of the ecosystem and create new environments for other living organisms [18]. They are also correlated to the composition of large benthic invertebrate communities, having a positive effect on the density of predators and scrapers, especially leeches, turbellaria, and mayflies of the order Ephemeroptera [22], while they exert negative impacts on the density of filtration-fed organisms, such as other species of Mollusca [23]. Another investigation indicated that zebra mussels influence other Mollusca, such as the bivalve group, by competing or interfering with their feeding, growth, movement, respiration and reproduction [21]. They can also reduce the amount of food available for fish and other aquatic living organisms. Table 3 shows a significant positive correlation between the presence of zebra and total densities of epiphytic algae estimated at (r=0.76) while a significant inverse relationship with other benthic invertebrates [24].

Table 3: Correlation coefficient between zebra and benthic invertebrates diagnosed during the study period in the sites in the Tigris River.

Taxa	Correlation coefficient –r	Sig.
Epiphytic	0.76	**
Protozoa	-0.63	**
Hydra	-0.19	NS
Rotifera	-0.55	*
Nematoda	-0.62	**
Turbellaria	-0.59	*
Annelida	-0.66	**
Cladocear	-0.62	**
Copepoda	0.42	*
Amphipoda	-0.51	*
Decapoda	-0.24	NS
Ostracoda	-0.55	*
Insecta	-0.66	**
Bivalava	-0.54	*
Gastropoda	-0.53	*
*** (P≤0.05). ** (P≤0.01), NS: Non-Significant.**		

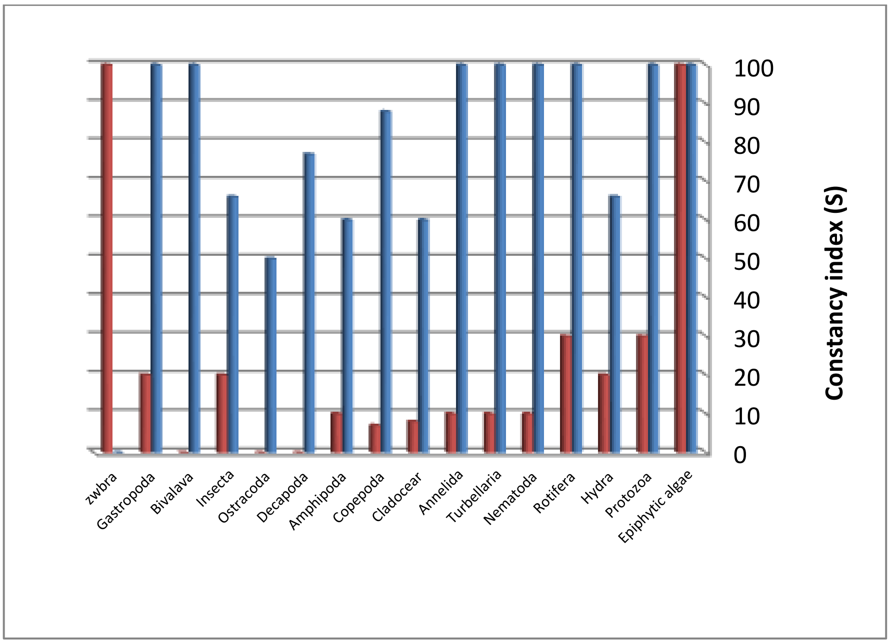


Figure 5: Benthic invertebrates constancy index (S) during the study period in the sites in the Tigris River.

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