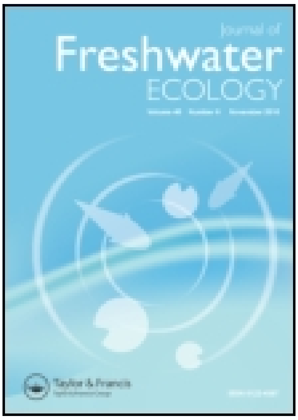


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# Seasonal changes in zooplankton communities in the re-flooded Mesopotamian wetlands, Iraq

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Non-directional re-flooding of the wetlands in southern Iraq, which were extensively drained during the 1990s, started in 2003. The change in species composition and abundance of rotifer and cladoceran communities together with their abiotic environment were studied for 15 months in the re-flooded wetlands. The re-flooded wetlands were characterized by higher salinity than typical freshwater inland marshes, and some rotifer and cladoceran species were characteristic of the saline, post-re-flooding environment. The changes in species composition and abundance of rotifers were mostly seasonal, demonstrated by the cyclic changes in principal component analysis and their positive relationships to water temperature. Al-Huwaiza Marsh is distinguished from the other two marshes (Central and Al-Hammar Marshes) and is characterized by relatively lower and stable salinity, close to neutral pH, near or above saturation DO, and lower $SO_4^{-2}$. These characteristics might explain the differences in recovery processes of zooplankton communities among the three marshes. The Jaccard's similarity index for *Cladocera* revealed similarity between the two stations of each marsh (in terms of maximum densities recorded); however, this was not mirrored by *Rotifera*. Al-Huwaiza Marsh stations were very similar to each other, whereas the Al-Hammar and Central Marshes had one station of each very similar to the other station of the other marsh. *Cladocera* and *Rotifera* are predominantly freshwater species; *Rotifera* is more sensitive to water quality changes, particularly salinity, than the *Cladocera*. The observed seasonal cycles of zooplankton communities might suggest that the system was stabilizing during the study period. However, water supply shortages since 2008 continue to threaten the wetlands.

**Keywords:** *Cladocera*; re-flooding; Mesopotamian wetlands; *Rotifera*; zooplankton; Jaccard's similarity index

## Introduction

The wetlands in southern Iraq represent extensive aquatic habitat in a region where freshwater is scarce. As a consequence, for at least the last 8000 years, all forms of life, including humans, have been drawn to and are dependent upon the wetlands (Heyvaert & Baeteman 2008). Thus, the deliberate destruction undertaken by the government during the 1990s and the reduction to <15% of the natural wetland extent are considered an environmental disaster (Maltby 1994; Munro & Touron 1996; Partow 2001). With the fall of the Iraqi Government in the spring 2003, the wetland region in southern Iraq was no longer off-limits. Local residents released water from artificial canals and reservoirs back

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onto the former wetlands on an *ad hoc* basis (Richardson et al. 2005). As of December 2006, it was estimated that water once again covered 58% of the pre-drainage wetland extent (UNEP 2008).

Zooplankton species are good ecological indicators of marsh environments because their physiological tolerances vary among species. Also, due to their location in aquatic food chains, changes in their populations reflect changes in the populations of their predators and prey. Furthermore, short life cycles and mobility allow quick responses to changes in environmental conditions.

*Rotifera and Cladocera* are two of the dominant taxonomic groups of freshwater zooplankton (Dodson & Frey 1991; Wallace & Snell 1991). Changes in species composition and abundance of rotifer and cladoceran communities were studied for 15 months in the re-flooded Mesopotamian wetlands with an aim to evaluate the restoration processes of the wetlands from the aspect of the temporal change in zooplankton communities. This is a part of the larger research initiative (CIMI, Canada Iraq Marshland Initiative) that includes research on other biological groups such as birds, fish, phytoplankton, and macrophytes.

Fortunately, historical scientific records of rotifers and cladocerans in the Mesopotamian wetlands extend more than 90 years (Gurney 1921) and were followed by recent studies including Al-Saboonchi et al. (1986), Abdul-Hussein et al. (1989), and Ali and Abdullah (1999) for rotifers and Al-Saboonchi et al. (1986), Salman et al. (1986), Ajeel (1998), Al-Zubaidi (1998), and Ajeel et al. (2006) for cladocerans. Existence of such pre-drainage zooplankton data from the Mesopotamian wetlands supports the approach taken.

The main goal of this study is to address the following questions:

(1) Are there differences in species composition and abundance in zooplankton communities among the three marshes?
(2) What environmental parameters might help to explain any observed differences?
(3) Were there any changes in species diversity and abundance in zooplankton communities in different seasons?



## Methods

### *Study sites*

The Mesopotamian Plain lies between the Iraq portion of the Arabian Shield and the foothills of the Zagros Mountains (Guest & Al-Rawi 1966). Extensive wetlands lie within the southern area of the Mesopotamian Plain at the confluence of Tigris and Euphrates Rivers (30.5°–32.5°N, 44°–48°E). At least 15,000 km$^2$ of wetlands, lakes, and rivers existed in the mid-1970s in this region (Rzóska 1980; Al-Hilli et al. 2009). The wetlands cover a large, flat, gently sloping clay-silt alluvial plain, occupying a large tectonic depression between the gypsum deposits of the Jezirah and Western Plateau of the Arabian Shield to the west, and the conglomerates, sandstones, and folded limestones of the Zagros Mountains to the east.

The climate of the Mesopotamian Plain is arid. Climatic data from Basrah show long-term (1920–1980) average annual temperatures of 24.4 °C, with the highest temperature (24 h average) at 34.5 °C in July and the lowest at 12.2 °C in January (World Climate 2005). Temperatures can reach 50 °C in summer and 0 °C in winter. Mean annual precipitation is about 100 mm on the northern edge of the wetlands and about 150 mm to the south. Annual evaporation is up to 3000 mm (Rzóska 1980).

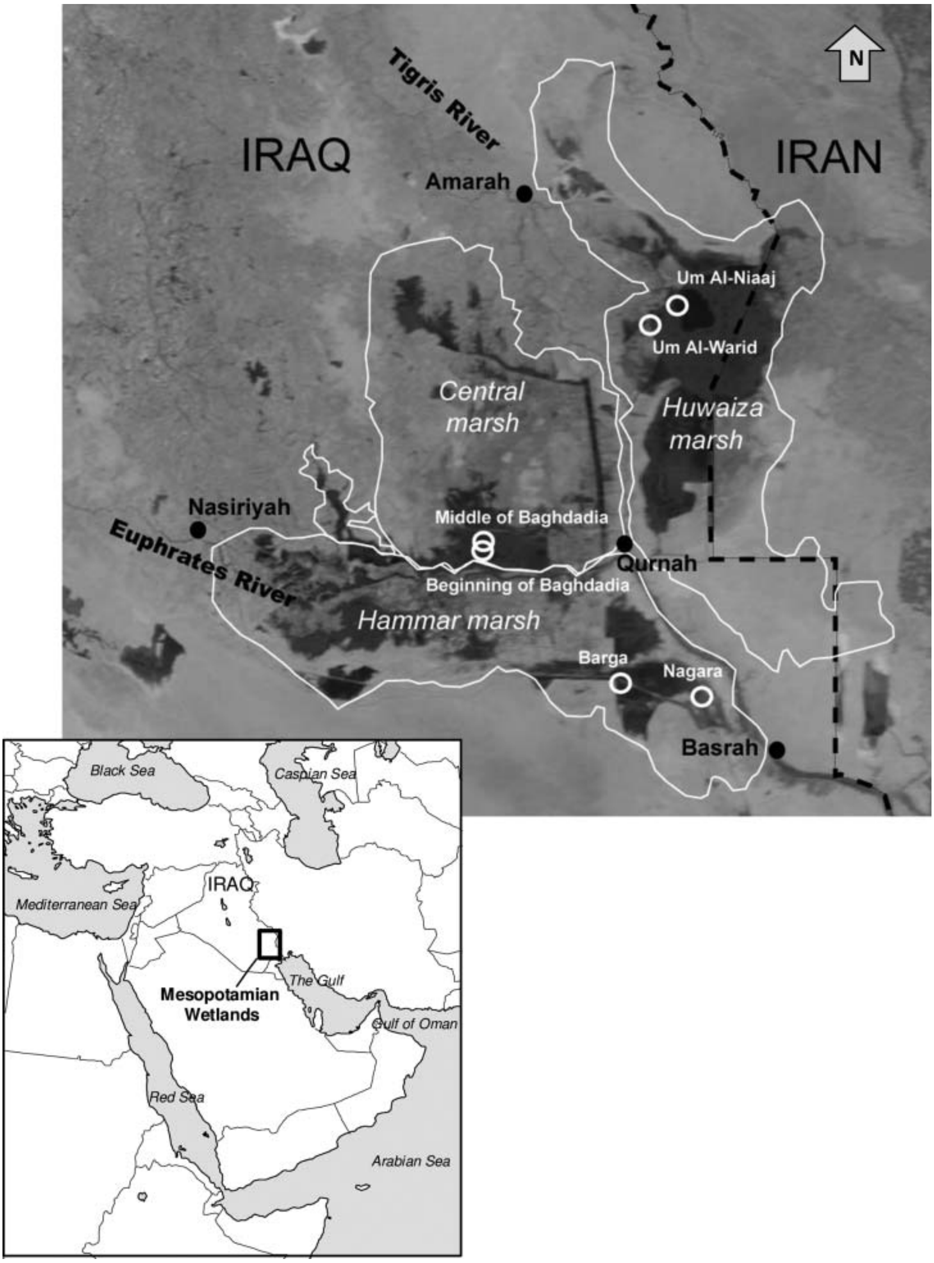


Figure 1. Six study sites shown on a satellite image taken by Aqua on 1 June 2006 (MODIS Rapid Response System, <http://rapidfire.sci.gsfc.nasa.gov/>). Dark gray areas are either dense vegetation or open water as a response to re-flooding. The thin white lines delineate the original three wetlands.

The Mesopotamian wetlands can be divided into three parts based on geographic position. The Al-Hammar Marsh to the south of the Euphrates River, the Al-Huwaiza Marsh to the east of the Tigris River, and the Central Marsh between the two rivers (Figure 1). The description of the three marshes is found in Partow (2001). Two study sites were established in each of the three marshes for this study.

Al-Hammar Marsh covers approximately 2800 km$^2$ during the dry season, expanding to over 4500 km$^2$ during the wet season. Al-Hammar Lake is the largest water body in Al-Hammar Marsh. It is shallow and eutrophic, and slightly brackish due to its proximity to the Arabian Gulf. Al-Hammar Marsh is fed primarily by the Euphrates River, but also considerably from the Tigris River, flowing over the Central Marsh. The largest oilfields in southern Iraq are located within or adjacent to Al-Hammar Marsh, including Rumaila, North Rumaila, and West Qurna.

The Nagara study site is located adjacent to the Shatt Al-Arab River. The water depth can reach 5 m at high tide and the water is highly turbid. Dominant macrophyte species include *Ceratophyllum demersum*, *Phragmites australis*, *Typha domingensis*, *Potamogeton perfoliatus*, *Najas marina*, and *Myriophyllum spicatum*. Salt residues are often observed on the macrophytes. The Barga study site is a shallow, open, clear water marsh. The dominant plant species were similar to those at the Nagara study site but more abundant. Filamentous algae are also abundant. Salt residues were observed but to a lesser extent than at the Nagara site.

The Central Marsh covers approximately 3000 km$^2$ during the dry season and expands to over 4000 km$^2$ during the wet season. The main water source of Central Marsh is the Tigris River and its southern end is the only area receiving water from the Euphrates River. Interspersed with several large, open water bodies, this freshwater marsh complex is otherwise densely covered by tall reeds. Re-flooding of Central Marsh mostly occurred in the southern sections of the marsh and two study sites, beginning and middle of Baghdadia, were established in this re-flooded area. The study sites are shallow, open water wetlands with water column average depths of 1.5 m. The water is calcareous and clear. Agricultural and fishery activities are common in the area. The northern end of the area is characterized by a dense network of tributaries where rice cultivation is extensive. Small villages exist near the study sites.

Al-Huwaiza Marsh covers between 2500 and 3500 km$^2$ during the wet season. The northern and central parts of the marsh are permanent, becoming seasonal southerly. Although drainage from Al-Huwaiza Marsh during the 1990s was the least among the three marshes, reductions in the Al-Huwaiza Marsh water inputs from Al-Karkheh River from Iran between 2003 and 2005 reduced the marsh area to 650 km$^2$ (CRIM 2006). The drainage changed the marsh landscape significantly and divided it into three distinct areas: the north-eastern sections which were never desiccated; the central sections which were partially or intermittently desiccated and re-flooded after 2004; and the southern sections which were completely desiccated and re-wetted after 2004. The Um Al-Naaj study site is the largest water body in Al-Huwaiza Marsh (between 140 and 200 km$^2$). Dominant plant species include *Phragmites australis*, *Ceratophyllum demersum*, *Potamogeton* spp., and *Najas* spp. Large villages such as Abu Khassaf are located near this study site. The Um Al-Warid study site is located south of Um Al-Naaj study site and they are connected through a channel. The water flows from the Um Al-Naaj study site to the Um Al-Warid study site when water levels are high. *Phragmites australis* grows densely in this study site and *Potamogeton* spp. are also dominant.

### *Field sampling and laboratory analyses*

Zooplankton was sampled monthly from November 2005 to January 2007. The samples were collected between 830 and 1000 each day. For sampling rotifers, a plankton net (53 $\mu$m) equipped by mouth diameter of 40 cm was used. It was pulled for 10 m just below the water surface. For *Cladocera*, a plankton net (120 $\mu$m) equipped by 30-cm mouth diameter was used. A flowmeter was mounted to the mouth of the net and towed for 10 minutes just below the water surface. Both rotifer and cladoceran samples were preserved in 4% formalin and transported to the laboratory for species identification and counting. To quantify rotifers, a 1 mL subsample was taken, poured into a Sedgewick-Rafter slide, and counted. The counting was continued by taking another 1 mL subsample after returning the previously counted 1 mL to the original sample. The counting was repeated until more than 100 individuals were enumerated and then the number per milliliters was recorded. In case of *Cladocera*, the samples with less than 100 individuals were sorted and counted as a whole. Whereas, for those with more than 200 individuals present, one or more subsamples of 10 mL each were taken from the original sample, until more than 100 individuals were recorded. In every case, a Wild™ dissecting microscope was used in counting and Zeiss™ compound microscope was used in identification. Species identification of rotifers was based on Edmondson (1959), Pontin (1978), and Kutikova (2002) and that of *Cladocera* was based on Brooks (1959), and Korinek (2002).

The environmental parameters were also monitored monthly from November 2005 to September 2006 at the same locations where zooplankton samples were collected. Water temperature, surface water pH, surface water electrical conductivity (EC), and dissolved oxygen (DO) were measured in the field with a portable multi-meter (WTW 340i/SET). Percent saturation of DO (%DO) was calculated based on the water temperature at sampling. A correction factor of 1.0 was applied for calculating %DO as altitudes of all the study sites were less than 5 m and EC was less than 5 mS/cm. Total suspended solids (TSS), total hardness (TH), chloride ($Cl^-$), and sulfate ($SO_4^{-2}$) in surface water samples were analyzed following APHA (2005). TSS was determined by weighing non-filterable residue (0.45-$\mu$m filter) dried at 103–105 °C. TH was determined by Ethylenediaminetetraacetic acid (EDTA) hardness titration, $Cl^-$ concentration by the argentometric method, and $SO_4^{-2}$ concentration by the turbidimetric method.

### *Statistical analysis*

*Rotifera and Cladocera* count data were analyzed separately with principal component analysis (PCA). Data were log-transformed and centered by species (i.e., covariance matrix). Environmental parameters were analyzed with partial PCA (Borcard et al. 1992). Month was used as a co-variable to exclude the effect of seasonality. Redundant parameters were removed from the ordination to avoid colinearity. Parameters that were not measured for the entire sampling period were not included in the ordination. Data were log-transformed, centered, and standardized (i.e., correlation matrix). *Rotifera and Cladocera* data were superimposed as supplementary variables.

## Results

A total of 105 taxa were identified at species level for rotifers and 22 taxa at genus level for cladocerans (Supplemental Tables 1 and 2). The PCA of rotifers showed monthly changes in species diversity, and the changes are nearly cyclic toward counter-clockwise direction (Figure 2). This monthly shift became clear after August 2006. Although November and December samples differed between 2005 and 2006, January 2007 samples were similar to January 2006 samples in terms of species diversity and abundance. The samples were more scattered for Al-Hammar and Central Marshes, and clustered centrally for Al-Huwaiza Marsh which also exhibited smaller temporal variation. For *Cladocera*, the monthly shift in species diversity was not as evident and the change was not

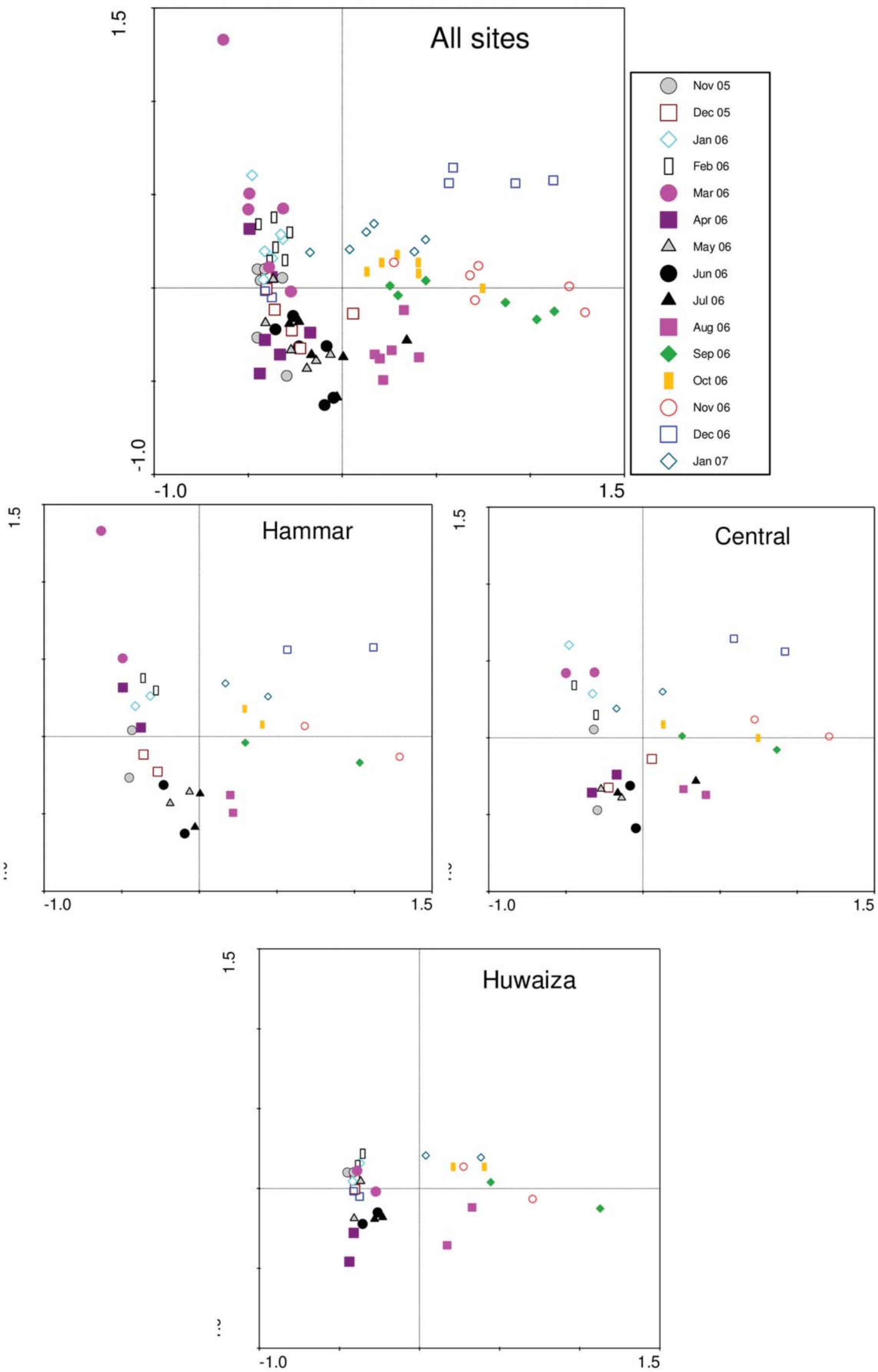


Figure 2. Scatter plots of principal component analysis (PCA) of *Rotifera* density data. Data were log-transformed and centered by species (covariance matrix). The percentage variance of species data explained by the first axis was 21.6% and the cumulative percentage by the first and the second axes was 32.3%.

cyclic but pendulatic (Figure 3). November 2005, December 2005, and January 2006 samples were similar to 2006 samples for the same months.

The densities of the 22 identified genera of *Cladocera* within the three marshes throughout the monitoring period (15 months) are presented in Supplemental Table 1. Generally, Al-Hammar Marsh contained higher densities of *Cladocera* than the Central and Al-Huwaiza Marshes; the latter of which had the lowest density. Out of the 105 taxa of *Rotifera* recorded in the study, 29 were chosen based on either total count, frequency, or maximum count, and presented in Supplemental Table 2.

Although sampling was scheduled on a monthly basis and the life cycles of most species of *Cladocera* are completed within a few months, some conclusions can be drawn from the present data for certain species. Seasonality in breeding is often noted in *Cladocera*. *Simocephalus*, *Diaphanosoma*, and *Alona* have extended periods of breeding for most of the year. At most locations, *Macrothrix* exhibited a much shorter breeding period (summer to autumn), yet at Um Al-Warid it bred in winter as well. *Chydorus*, on the other hand, bred in winter and spring. *Pleuroxus* bred mainly in autumn (as in Al-Hammar Marsh, Al-Barga), but breeding was detected in winter and spring in other stations. *Pseudosida*, *Latonopsis*, and *Daphnia* were occasionally sampled but they were likely to breed in autumn. *Ilyocryptus* and *Graptoleberis* bred in winter and *Camptocercus* and *Bosmina* bred in spring.

Breeding in *Rotifera* occurred on a much shorter time scale than *Cladocera*. Data from each station was grouped seasonally and conclusions drawn for all stations collectively. *Brachionus calyciflorus*, *B. plicatilis*, *Keratella valga*, *Lepadella* sp., *Monostyla closterocerca*, *Asplanchna* sp., *Monostyla* sp., and *Synchaeta* sp. bred year round. Other species excluded certain seasons for breeding such as *B. quadridentatus* (autumn), *Euchlanis* sp. (spring), *T. tetractis* (spring), *Keratella quadrata* (summer), *K. valga* (summer), *L. ovalis* (winter), and *Testudinella* (spring, summer).

Jaccard's similarity index of the *Cladocera* and *Rotifera* at the two stations of each of the three marshes showed substantially different situations. In the case of the *Cladocera*, the three marshes are quite distinct from each other (Figure 4), with the two stations of Al-Hammar Marsh showing 66% similarity, the two stations of the Central Marsh showing 52%, and the Al-Huwaiza Marsh showing 49%. The *Rotifera* exhibited quite different groupings. Al-Huwaiza Marsh stations were close with 84% similarity but the sites in the other two marshes were less similar to each other. For instance, Al-Nagara of Al-Hammar Marsh indicates 64% similarity with Al-Baghdadia center of the Central Marsh and Al-Barga station of Al-Hammar showed 69% similarity with Al-Baghdadia Beginning station (Figure 5).

Water temperature showed clear seasonality and was similar in all the three marshes (Figure 6). For most of the other environmental parameters, Al-Huwaiza Marsh (Um Al-Naaj and Um Al-Warid study sites) showed smaller temporal variations than the other two marshes.

All the study sites had higher salinity than typical inland freshwater marshes (Figure 6). EC and $Cl^-$ showed similar temporal changes and the values were consistently higher in Al-Hammar and Central Marshes than in Al-Huwaiza Marsh. The pH was alkaline in winter and nearly neutral in summer and fall (Figure 6). Temporal fluctuation was the greatest at the beginning of Baghdadia study site in Central Marsh, and the smallest at Um Al-Naaj study site in Al-Huwaiza Marsh. Percent DO was higher than saturation most of the time at Um Al-Warid study site in Al-Huwaiza marsh (Figure 4). The two sites in Al-Huwaiza Marsh showed higher %DO in summer than in winter and spring. Conversely, the two sites in the Central Marsh showed lower %DO than saturation

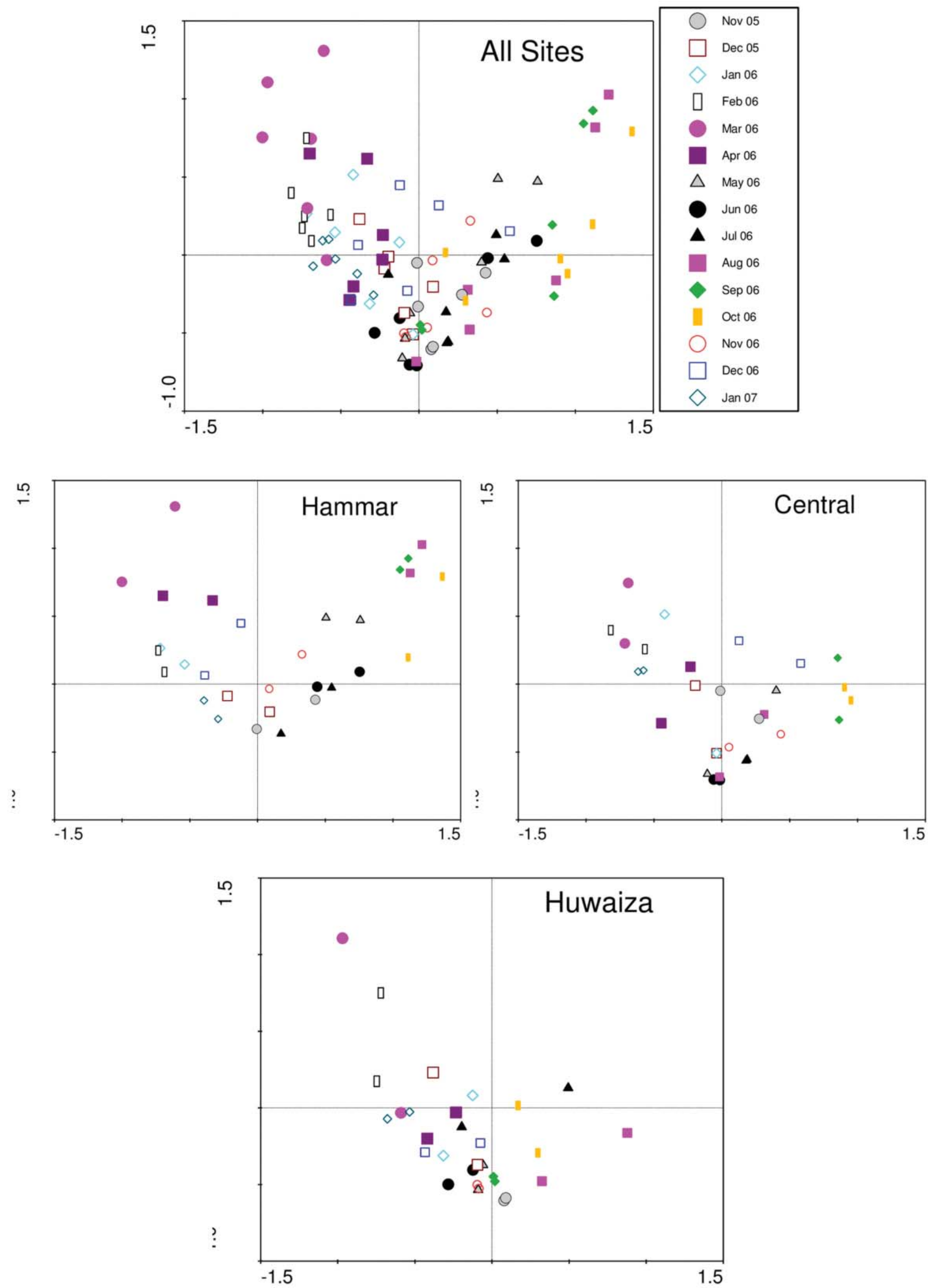


Figure 3. Scatter plots of principal component analysis (PCA) of *Cladocera* density data. Data were log-transformed and centered by species (covariance matrix). The percentage variance of species data explained by the first axis was 30.2% and the cumulative percentage by the first and the second axes was 50.8%.

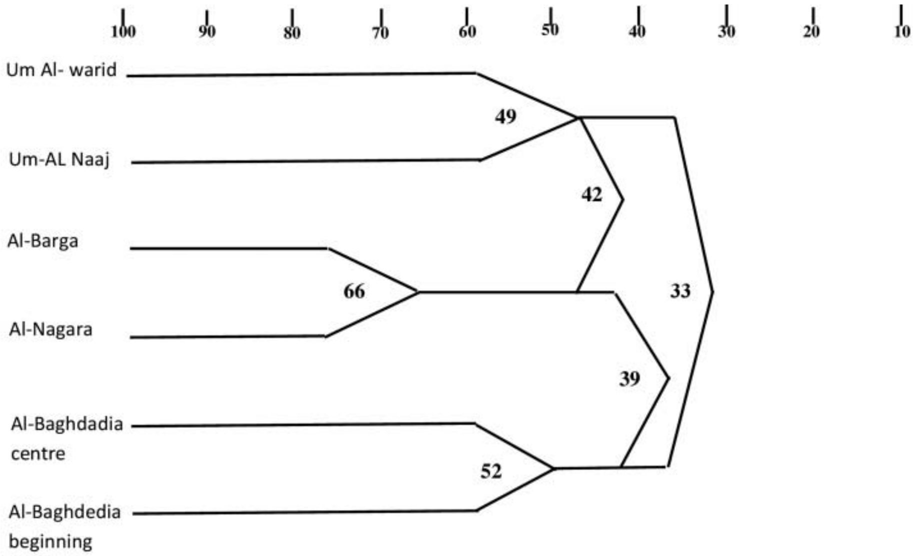


Figure 4. Jaccard's similarity index of *Cladocera* in selected marshes.



throughout the sampling period. It was especially low in summer. %DO in Al-Hammar Marsh in summer was in between Al-Huwaiza and Central Marshes.

TSS was generally higher in summer and fall than in winter and spring at most of the study sites (Figure 4). The increase of TSS in summer was the greatest at Um Al-Warid study site in Al-Huwaiza Marsh. Seasonal fluctuation of TH was greater in Al-Hammar and Central Marshes while less in Al-Huwaiza Marsh. There was an increase in TH in July in the former two marshes but not in Al-Huwaiza Marsh. $SO_4^{-2}$ was very high for freshwater wetlands in general. $SO_4^{-2}$ in Al-Hammar and Central Marshes showed higher

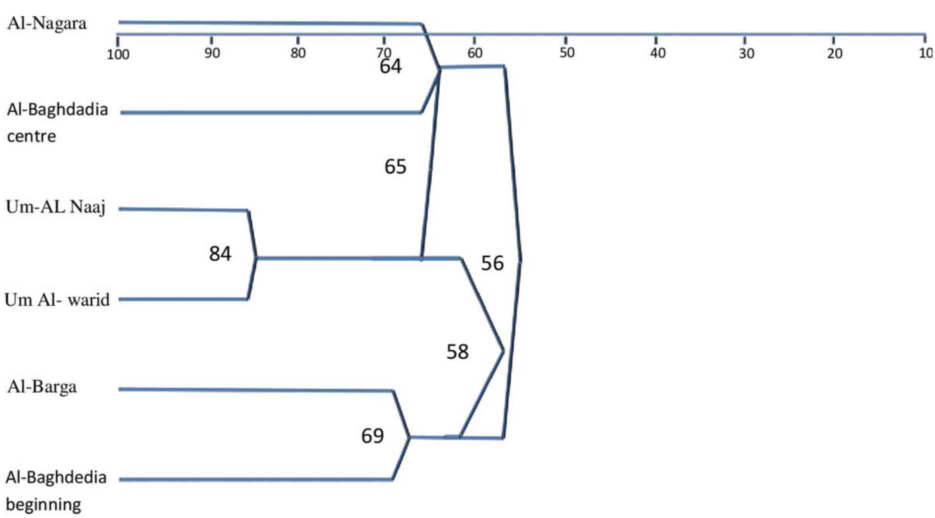


Figure 5. Jaccard's similarity index of *Rotifera* in selected marshes.

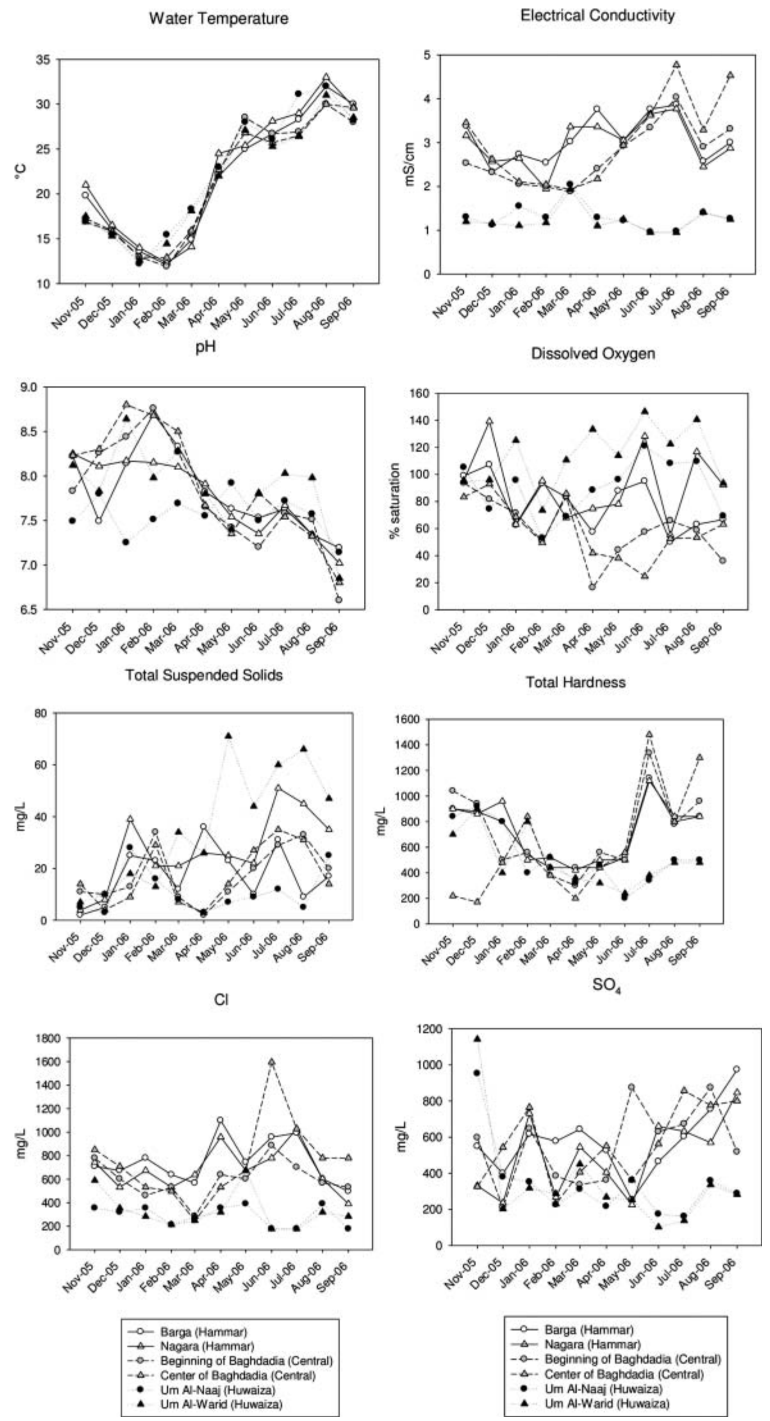


Figure 6. Monthly changes in environmental parameters during the study period.

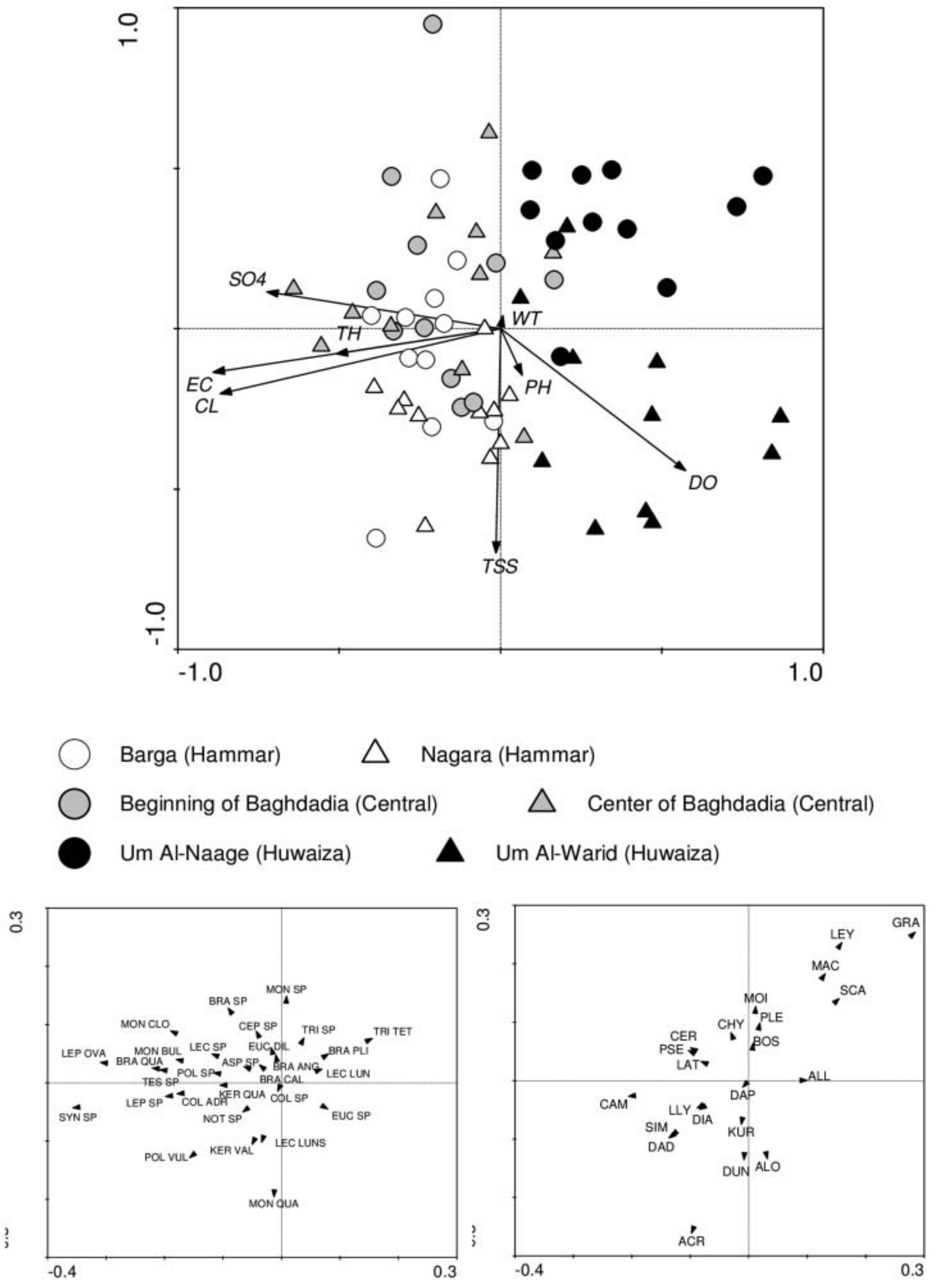


Figure 7. Tri-plot of partial principal component analysis (partial PCA) of monthly environmental parameters from November 2005 to September 2006. The effect of seasonal variations of environmental parameters on PCA was removed from the ordination by designating months as a covariable. *Rotifera and Cladocera* data were superimposed as supplementary variables in PCA and plotted separately (two diagrams in the bottom) from the main ordination diagram (top) for clarity. Rotifers were ranked by total count, frequency, or maximum count in any of the samples and all cladocerans or the top 29 rotifer species are presented. Data were log-transformed, centered, and standardized. Samples were classified by sites. See Supplemental Table 1 for the species codes and text for environmental parameter codes. The percentage variance of environmental parameter data explained by the first axis was 53.7% and the cumulative percentage by the first and the second axes was 69.5%.

Table 1. Linear regressions with water temperature as the independent variable $x$ in $y = ax + b$ ($n = 66$). Ordination diagrams of principal component analysis (PCA) are shown in Figure 2 for *Rotifera* and in Figure 3 for *Cladocera*.

| Dependent ($y$) | | Constant ($b$) | Slope ($a$) | Adjusted $r^2$ | $F$ | $p$ |
|---|---|---|---|---|---|---|
| *Rotifera* | PCA axis 1 score | −0.924 | 0.0350 | 0.398 | 43.977 | <0.001 |
| | PCA axis 2 score | 0.646 | −0.0327 | 0.401 | 44.505 | <0.001 |
| | Total count ($L^{-1}$) | −0.452 | 0.3480 | 0.240 | 21.581 | <0.001 |
| | Species richness | 2.287 | 0.5650 | 0.325 | 32.353 | <0.001 |
| *Cladocera* | PCA axis 1 score | −1.353 | 0.0604 | 0.526 | 73.147 | <0.001 |
| | PCA axis 2 score | 0.292 | −0.0127 | 0.013 | 1.860 | 0.177 |
| | Total count ($m^{-3}$) | 369.289 | 17.4860 | 0.000 | 0.462 | 0.499 |
| | Species richness | 12.319 | −0.1830 | 0.109 | 8.968 | 0.004 |

values in summer but not in Al-Huwaiza Marsh (Figure 4). In Al-Huwaiza Marsh, $SO_4^{-2}$ was stable most of the time except in the first month of the study period.

Water temperature, which indicates seasonality, and both the PCA axes 1 and 2 scores of rotifers were significantly correlated with water temperature. Total count and species richness of rotifers also were correlated significantly with water temperature (positively). Conversely, water temperature was not correlated with parameters of species diversity and abundance of *Cladocera* except for PCA axis 1 scores.

Al-Huwaiza and the other two marshes were clearly separated along the first axis of the partial PCA of environmental parameters (Figure 7, Table 1). This separation is explained mostly by lower salinity, lower $SO_4^{-2}$, and higher DO in Al-Huwaiza Marsh than Al-Hammar and Central Marshes. Within Al-Huwaiza, Um Al-Warid study site was characterized by higher TSS and DO than Um Al-Naaj study site. Although the association of species to measured environmental parameters was not strong, shown by the shorter ordination axes of the species subplots (two subplots at the bottom of Figure 5), some trends can still be recognized. For example, distribution of *Synchaeta* sp. and *Lepadella ovalis* are marginally associated with higher salinity and that of *Graptoleberis*, *Leydigia*, *Macrothrix*, and *Scapholeberis* with lower salinity.

## Discussion

The results indicate that Al-Hammar Marsh has a larger density of zooplankton than Al-Huwaiza and the Central Marsh, and that the Al-Huwaiza Marsh has the lowest zooplankton counts. This illustrates that Al-Hammar Marsh, although historically subjected to considerable drying, remains healthier than the other two marshes, based on zooplankton populations. This is likely attributed to continually circulating waters in Al-Hammar, compared to the other two marshes. Al-Huwaiza Marsh has experienced deterioration of water quality, due to Iranian flow restrictions (a dike along the Iran–Iraq border) preventing influx of freshwater into Al-Huwaiza.

The Jaccard's similarity index (Figure 4) for *Cladocera* revealed similarity between the two stations of each marsh in terms of maximum densities recorded; however, this was not duplicated by *Rotifera*. Al-Huwaiza Marsh stations were very similar to each other, whereas, the Al-Hammar and the Central Marshes had one station of each similar to a station of the other marsh. *Cladocera* and *Rotifera* are predominantly freshwater species; the *Rotifera* is more sensitive to water quality changes, particularly salinity, than the *Cladocera*.

The species composition and abundance of zooplankton communities showed changes with time during the 15-month study period. In particular, rotifer communities showed clear cyclic changes as demonstrated in PCA. These cyclic changes of rotifer communities are probably associated with seasonal cycles of environmental conditions in the marshes. Temperature has been found to be the primary factor explaining the seasonal patterns of zooplankton communities in other saltwater, brackish-water, and freshwater tidal systems (Tackx et al. 2004), and the significant correlation of water temperature to parameters related to species composition and abundance was shown in this study as well (Supplemental Table 2). Our results suggest that higher temperature in summer leads to increase in rotifer population and species richness, and the seasonal variations in temperature leads to shift in species composition.

The seasonal increase in rotifer population and richness may also be related to the increase in their food source that depends on temperature. As part of the CIMI project, chlorophyll-a concentration was monitored at Um Al-Warid and Um Al-Naaj study sites in Al-Huwaiza Marsh from May 2006 to April 2007 (AlMaarofi et al. 2014). At Um Al-Warid study site, the peak of chlorophyll-a concentration was observed in August 2006. The total rotifer count at Um Al-Warid study site also peaked in August 2006 and their species richness also increased greatly in the same month. The TSS also increased in summer at Um Al-Warid study site, which also suggests more food available in summer. However, the similar trend was not observed at Um Al-Naaj study site. The seasonal trends of cladoceran population did not correlate with chlorophyll-a concentration either.

The Mesopotamian wetlands are characterized by higher salinity than the typical freshwater inland marshes mostly due to low precipitation and high evaporation rates. The salinity increased after re-flooding and chloride concentrations were found to be more than three times higher in 2006 than in 1970s in the re-flooded Central Marsh (Maulood et al. 1979; Hamdan et al. 2010). During the decades of drying periods, salts accumulated on the sediment surface and were probably flushed into the re-flooded water. High evaporation rates, high temperatures, and water stagnation caused by dam construction would have contributed further to the rise in salinity. *Moina* was the most abundant genus of *Cladocera* in the studied marshes (Supplemental Table 1). This genus is known to be typical in saline and alkaline lakes (Levi 1982) with a salinity tolerance higher than sea water (Dodson & Frey 1991). *Moina* was most abundant in August, September, and October in most of the study sites, which coincides with the months of the highest salinity. As most cladocerans are sensitive to salinity (Dodson & Frey 1991), relatively small numbers of cladoceran species and the high abundance of *Moina* is typical of the saline condition of the re-flooded marshes. *Keratella* and *Polyarthra* are abundant in the study sites and they are the most common pelagic rotifers (Nogrady 1982). Most species in *Synchaeta* are known as pelagic as well (Wallace & Snell 1991) and they characterized the rotifer communities at high salinity in this study (Figure 2). If the restoration goal is to restore the original biological communities before drainage, monitoring zooplankton communities could be one of the tools coupled with the monitoring of other biological groups. Decreasing the abundance of salt-tolerant genera, such as *Moina*, *Keratella*, *Polyarthra*, and *Synchaeta*, and increasing species richness of other cladocerans might suggest the decreasing salinity in the marshes.

The pH was very alkaline in some of the re-flooded Mesopotamian wetlands in winter, and this could also affect the zooplankton communities. *Brachionus plicatilis* is one of the abundant rotifers in this study, which is common in alkaline and brackish waters because it tolerates high osmolarities (Wallace & Snell 1991). The high pH is probably related to both dissolution of salts on re-flooding and an increase in $HCO_3^-$ concentration after re-flooding (more than 30 times in Central Marsh; Hamdan et al. 2010). The buffering effect of atmospheric $CO_2$, which usually occurs for rivers, would have been overpowered by the high $HCO_3^-$ concentration. Summer pH was moderate, and declined to 7 or less by September 2006. This is likely due to both dilution and an increase in decomposition rates late in the summer. Data do not exist for pH during winter periods after 2007.

Restoration may proceed differently among the three marshes because environmental conditions are not uniform among them. Al-Huwaiza Marsh is distinguished from the other two marshes by its unique environmental conditions. It is characterized by relatively lower and stable salinity, close to neutral pH, DO at or above saturation, and lower $SO_4^{-2}$. The salinity has been found to explain the spatial differences in zooplankton communities in other studies (e.g., Tackx et al. 2004). As the two study sites in Al-Huwaiza Marsh were not drained completely, accumulation of salts during desiccation periods and their dissolution on re-flooding would have been smaller than the other study sites. While the Tigris River, which contains less dissolved minerals because it is under greater influence of mountain forest and moist steppe vegetation, provides water into Al-Huwaiza Marsh, the Euphrates River, which tends to be rich in calcium carbonate and gypsum because most of its drainage basin is under the influence of desert and arid steppe, provides water to Central and Al-Hammar Marshes. This difference in water sources could also explain the less saline condition in the Al-Huwaiza Marsh. Higher gypsum concentration in the Euphrates River could also attribute to higher $SO_4^{-2}$ in the re-flooded Al-Hammar and Central Marshes than the Al-Huwaiza Marsh because of the diffusion and advection of $SO_4^{-2}$ from gypsum dissolution in sediments (Markel et al. 1998). Such environmental differences would not only directly affect the zooplankton themselves but also indirectly control their population by affecting their predators and prey in the wetlands. The smaller seasonal change in rotifer composition in Al-Huwaiza Marsh than the other two marshes might be explained by such environmental characteristics (Figures 2 and 6).

Certainly, Um Al-Warid is healthier than Um Al-Naaj, as it receives water from Al-Adil River that passes through Al-Amara City; therefore, the water is known to have elevated TSS and high DO, probably due to the fact that it is a running water. Low pH values are due to heavy growth of aquatic vegetations in the area. Um Al-Naaj, on the other hand, comprised stagnant water and anoxic conditions at depth. These conditions are likely due to dike construction closing the basin to renewable water. Hence, it is not surprising to have water quality deterioration.

The observed seasonality of zooplankton communities might suggest that the system was stabilizing during the study period. If the change had been controlled only by the factors related to recovery phases of the marshes after re-flooding, directional rather than seasonal cycles would have been observed. In this sense, the study identified progress of ecosystem rehabilitation of the Mesopotamian wetlands after the re-flooding. Many macrophyte species and communities also responded well after the re-flooding (Hamdan et al. 2010). Unfortunately, however, the wetlands continue to have reduced water supply since 2008 and large areas of the wetlands remain desiccated. The future of the Mesopotamian wetlands is still uncertain.

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## Supplemental data

Supplemental data for this article can be accessed here.

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