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Original Article

The Al Wathba Wetland Reserve Lake in Abu Dhabi, United Arab Emirates and its ostracod (seed shrimp) fauna

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Abstract: Al Wathba Wetland Reserve (AWWR) lake, in the United Arab Emirates (UAE), is an artificially created water body in a natural wetland region that experienced seasonal flooding before the establishment of the lake. The lake is mostly fed by treated waste water, and became a protected wetland reserve after the Greater Flamingo started to successfully breed in the area in 1998. Detailed monitoring of several hydrochemical parameters and water depth at nine stations and two inlets of treated water in the lake was conducted over a period of seven years starting in January 2010. As a result, the seed-shrimps (Ostracoda: Podocopida) *Heterocypris salina*, previously reported from a late Miocene location in the UAE, and *Cyprinotus cingalensis* were recorded for the modern fauna of the UAE for the first time. The presence of the ostracods only at the station with the lowest salinity in the AWWR Lake shows that their distribution is predominantly controlled by the salinity of the water which covered an extremely large range of more than two orders of magnitude (1.45-457‰) at the different sampling sites and inlets during the monitoring period. Thus, the lake represents an interesting and important ecological research laboratory under semi-natural conditions.

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Introduction

Terrestrial surface waters are rare in arid regions and they represent important biodiversity hotspots of the aquatic and terrestrial flora and fauna, including migratory birds, amphibians and mammals in lake, wetland and gallery forest regions. Dryland lakes often support local fisheries and provide recreational services. Natural surface waters in western and central Asia are often endangered due to man-made hydrological changes such as water withdrawal for irrigation farming and due to increasingly frequent extreme weather conditions as a result of global climate change (Lelieveld et al., 2012). The desiccation of the Aral Sea, the rapidly falling level of the Dead Sea and the disappearing Lake Urmia are the most prominent and serious examples (Micklin, 1988; Tourian et al., 2015; Willner et al., 2015). Knowledge of the state of local surface waters in arid regions is urgently required to understand their ecological and societal significance, and to assess their vulnerability to human impacts and global climate change.

An important component of aquatic ecosystems such as Al Wathba is the micro-crustacean fauna. Among micro-crustaceans, the ostracods form a widely distributed and diverse group which occupies all types of aquatic or even semi-aquatic environments (the ocean, marginal marine settings such as lagoons and estuaries, saline and freshwater lakes, rivers, wetlands, springs, wet leaf litter, etc.). The ostracods have two calcitic valves that enclose the soft body and form a carapace typically 0.5-2.0 mm long. More than 65,000 living and fossil ostracod taxa at or below the species level have been described (Kempf, 1997). We here present a study of a man-made lake in the UAE with a focus on its spatial and temporal water-chemistry characteristics and a first record of its ostracod (micro-crustacean) fauna.

Materials and Methods

The Al Wathba Wetland Reserve (AWWR) Lake is located on the coastal sabkha plain ca. 40 km southeast of Abu Dhabi Island (Fig. 1). The partly

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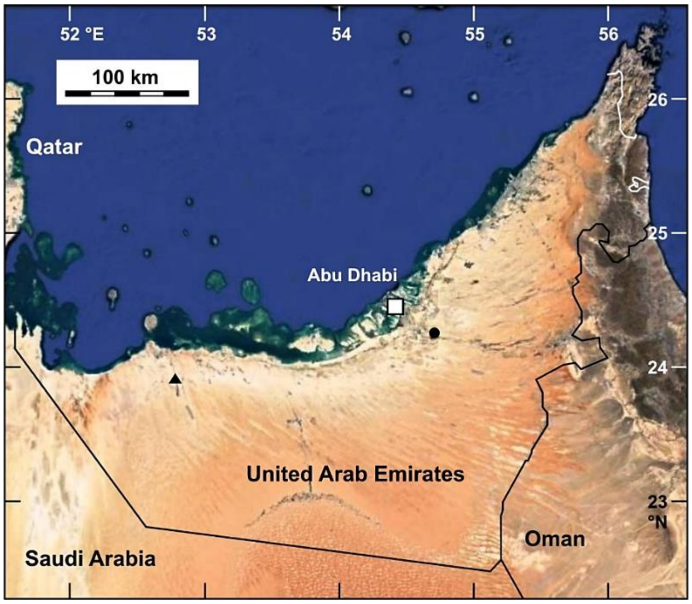

Figure 1. Al Wathba Lake in the Al Wathba Wetland Reserve in the UAE (green dot) and the location of a late Miocene record of the ostracod *Heterocypris salina* (triangle).

dune-covered sabkha in the lake area lies 15-18 m above sea level. The region represented a seasonally flooded wetland with temporarily rising water levels probably resulting from increasing sub-surface water flow and hydrostatic pressure from stronger winds and higher tides in winter (Al Dhaheri, 2004). The construction of the Mussafah - Al Ain Truck Road between 1980 and 1984 dammed the southward flow of surface waters and increased the area and annual duration of emerging surface waters, and the abundance of waterfowl. The ecological potential of the wetland for local birdlife was recognised and AWWR Lake established as a perennial water body mostly fed by treated waste water from the Mafraq Wastewater Treatment Plant, which is the main sewage treatment plant of the city of Abu Dhabi (Fig. 2). The permanent water body attracts a diverse birdlife and became protected as Al Wathba Wetland Reserve since 1998 due to the first successful breeding of the Greater Flamingo (*Phoenicopterus roseus*) on the Arabian Peninsula since a last record in 1922 from Kuwait (Ticehurst, 1926). Its high biodiversity including 260 bird species (Soorae et al., 2014) led to the declaration as an internationally recognised and protected Ramsar wetland site in 2013. The protected wetland has an area of ca. 5 km² and the lake surface

Figure 2. Sampling stations ST 1 to 10 and the inlet water valves I and II of the wastewater treatment plant (WWTP). Ostracods were exclusively recorded at station 8.

covers ca. 1.6 km² (Al Dhaheri, 2004). The maximum water depth of the lake is 2.3 m.

The AWWR is managed by the Environment Agency Abu Dhabi (EAD) and mainly used for research, education and eco-tourism including bird-watching today. The salinity of AWWR Lake is variable due to the fresh water input and the underlying sabkha substrate. However, most of the lake is hyperhaline with a mean salinity of ca. 200‰ between 2010 and 2014 (Saji et al., 2016). During the same period, mean monthly values of water temperature, pH and dissolved oxygen concentration ranged from 22.8-35.9°C, 7.0-8.6, and 3.7-7.9 mg L^{-1}, respectively (Saji et al., 2016).

Mixed plant communities of *Zygophyllum qatarense*, *Haloxylon salicornicum*, *Dipterygium glaucum*, *Anabasis setifera* and *Tamarix* cf. *ramossisiima* dominate the vegetation, with *Phragmites australis* reed beds along the less brackish margins of the lake (Al Dhaheri, 2004) (Fig. 3). The mean January and July temperatures are 19.8 and 35.8°C, respectively, and mean annual temperature is 28.1°C (NCMS, 2017). Mean annual precipitation in the region is ca. 100 mm, mostly occurring between December and February, and mean annual evaporation in the order of 2000 mm (Abdelfattah and Meharibi, 2005; SCAD, 2015).

Water samples were collected within the frame of an *Artemia* research programme from nine stations

Figure 3. Typical scenery of the Al Wathba Lake.

(ST 01 to ST 10, ST 09 excluded due to mostly dry conditions) in the lake and two inlets (Inlets I and II) on a quarterly basis between 2012 and 2015 and on an almost complete monthly basis in 2010, 2011 and 2016. This programme was established by the Terrestrial Environment Research Center of the Environment Agency - Abu Dhabi in 2001 to monitor *Artemia* as most important food source for birdlife and especially the Greater Flamingo in the AWWR. The sampling sites for *Artemia* were chosen based on a 100 m grid overlaid on AWWR Lake. The samples were collected with a Van Dorn water sampler (2.2 L) from the water column below the water surface. The two inlets were not examined for the presence of *Artemia* or ostracods. The water was passed through a 20 µm plankton net and the retained organisms examined using a Zeiss Stemi 2000 low-power binocular microscope. The presence of ostracods was checked on a regular basis and the identification of taxa is based on two samples of 23 March (sample 1) and 22 June 2016 (sample 2) which were stored in 70% ethanol. Identification was aided by the use of a Zeiss Supra 40VP scanning electron microscope at the Institute of Geological Sciences of the Free University of Berlin (Germany) and is based on descriptions of (Malz, 1976; Meisch, 2000). Voucher specimens in ethanol are deposited in the wet collection of the Invertebrate collection of the Environment Agency - Abu Dhabi (ICEAD).

The water depth was recorded at each station with a measuring metre scale. A hand-held WTW 350i was used to measure pH and temperature. Salinity was mostly measured in the lab using sub-samples of water samples diluted with distilled water. Lab analyses of water samples focused on nitrogen (as nitrate, nitrite and ammonia), phosphate (as PO_4), total organic carbon (TOC) and heavy metals Copper (Cu), Cadmium (Cd) and Iron (Fe), and followed standard procedures (U.S. Environmental Protection Agency, 1983; Saji et al., 2016). All the data were presented in graphs drawn using CoralDraw V.12 and Grapher (Golden Software V.3). Figure 7 was prepared using Corel Photo-Paint and CorelDraw and the map of Figure 9 was created in amCharts software.

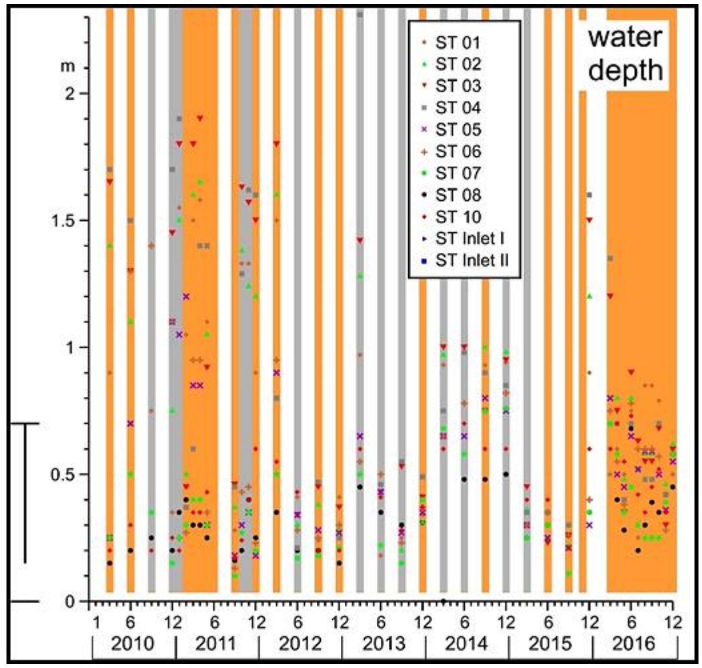

Figure 4. Water depth data for the sampling stations (ST) during the years 2010 to 2016. Grey vertical bars indicate months during which water samples were unsuccessfully examined for the presence of ostracods and orange bars represent months during which ostracods were present at ST 08. The two horizontal lines at the left show the water depth range at ST 08 during the monitoring period and the vertical line in between these lines indicates the water depth range for the ostracod records at ST 08. ST 08 was dry in March 2014 and ostracods were not recorded.

Results

The water depth at the sampling stations changed over the observation period by a minimum of 0.56 m at ST 10 to a maximum of 2.10 m at ST 04 (Fig. 4). The salinity ranged from 1.45‰ at inlet I to 457‰ at ST

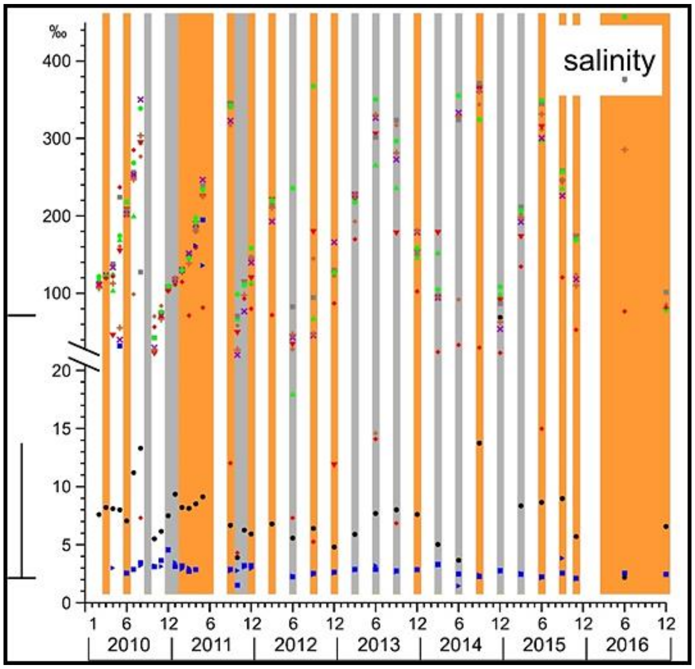

Figure 5. Salinity data and ostracod records in the years 2010 to 2016 shown in a similar way as for water depth in Figure. 4. (Refer to Fig. 4 for symbols of the sampling stations).

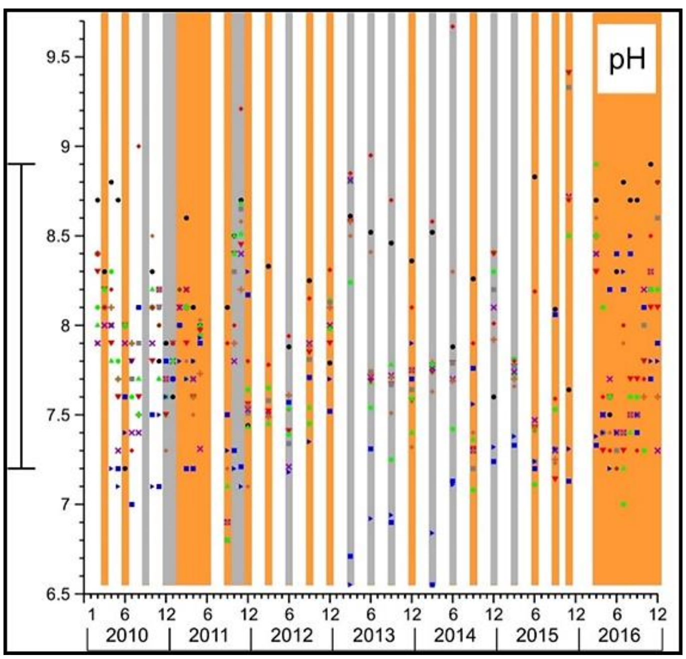

Figure 6. pH data and ostracod records in the years 2010 to 2016. (Refer to Fig. 4 for symbols of the sampling stations).

07 (Fig. 5). The pH value was lowest with 6.55 at inlet I and highest with 9.67 at ST 10 (Fig. 6). Nitrate concentrations were lowest at ST 08 with <0.03 mg L^{-1} and highest at ST 10 with 771.66 mg L^{-1} (Fig. 8a). Nitrite concentrations ranged from <0.03 mg L^{-1} at ST to 9.07 mg L^{-1} at inlet I (Fig. 8b). Ammonia concentrations were as low as <0.02 mg L^{-1} at STs 07

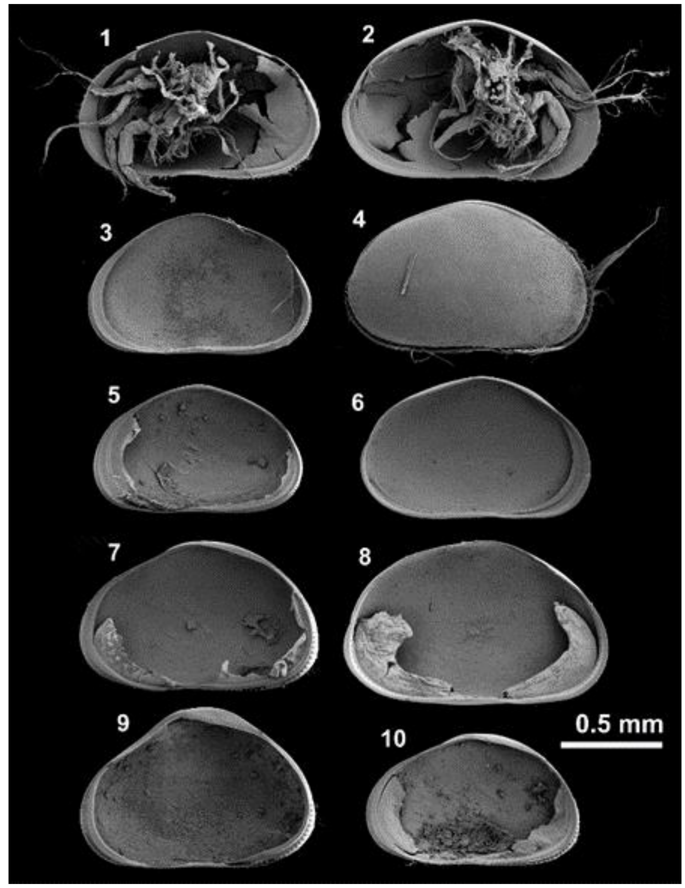

Figure 7. The ostracods *Heterocypris salina* (1-6) and *Cyprinotus cingalensis* (7-10) from AWWR Lake. *Heterocypris salina*: (1) right valve (RV) with anterior soft parts, 2 left valve (LV) with anterior soft parts, 3 RV, 4 carapace with RV fully visible, 5 juvenile RV, 6 LV; *Cyprinotus cingalensis*: 7 RV, 8 LV, 9 RV with more pronounced "hump", 10 juvenile RV. All images apart from 4 show internal views of valves. Specimens housed at Institute for Geological Sciences of the Free University of Berlin, Germany.

and 10 and as high as 18.7 mg L^{-1} at ST 03 (Fig. 8c). Phosphate concentrations were in a range from <0.2 mg L^{-1} at STs 01 to 07 and ST 10, to 20.88 mg L^{-1} at inlet II (Fig. 8d). TOC concentrations were between 2.4 mg L^{-1} at inlet I and 257.3 mg L^{-1} at ST 10 (Fig. 8e). Concentrations of Cd were often below detection limit (<0.0005 mg L^{-1}) and reached a maximum of 1.62 mg L^{-1} at inlet I (Fig. 8f). The Cu concentrations were also often below detection limit (<0.005 mg L^{-1}) and a maximum of 26.94 mg L^{-1} was determined for inlet I (Fig. 8g). Concentrations of Fe remained also often below detection limit (0.05 mg L^{-1}). A highest value of 259.2 mg L^{-1} was recorded at inlet II (Fig. 8h).

Ostracods were exclusively recorded at ST 08 during the course of the observations between the

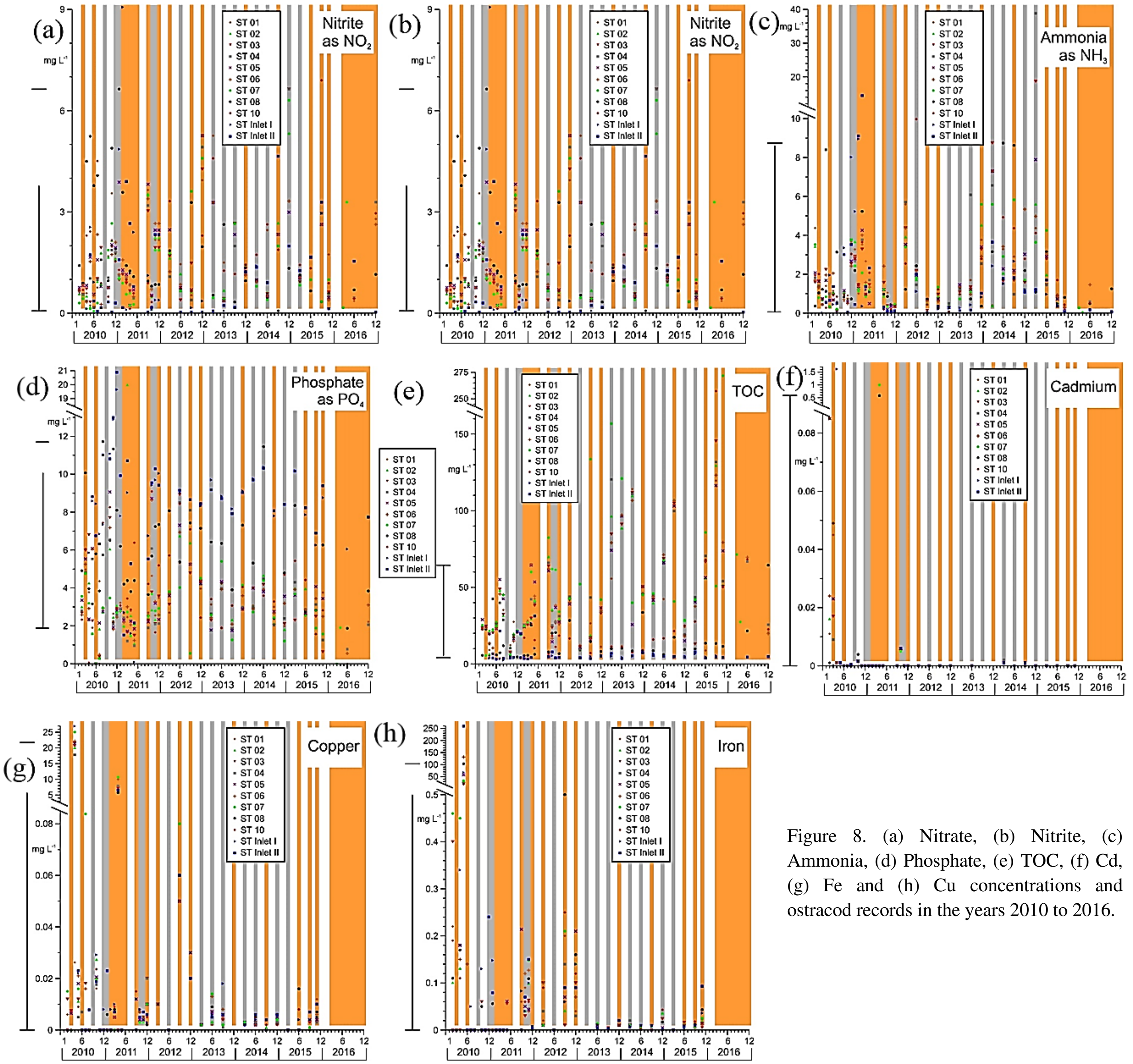

Figure 8. (a) Nitrate, (b) Nitrite, (c) Ammonia, (d) Phosphate, (e) TOC, (f) Cd, (g) Fe and (h) Cu concentrations and ostracod records in the years 2010 to 2016.

years 2010-2016. Ostracods were present during two thirds (27) of the 41 surveys at ST 08 (Fig. 4). Sample 1 collected on the 23 March 2016 contained juvenile and adult specimens of *Heterocypris salina* (Brady, 1886) (Fig. 7). Sample 2 from the 22 June 2016 included juvenile and adult specimens of *H. salina* and of *Cyprinotus cingalensis* (Sohn and Morris, 1963) (Fig. 7). The specimens of *H. salina* are more abundant than those of *C. cingalensis* in sample 2.

Discussion

The occurrence of *C. cingalensis* in the AWWR Lake represents the first record of the species from the UAE. Valves or living specimens of *C. cingalensis* were recorded so far from Saudi Arabia, Yemen including Socotra Island, Sudan, Palestine, Sri Lanka, India, Indonesia, the Philippines, Japan, Australia and Hawaii given that some records as *C. scholiosus* and *Cheikella scholiosa* represent junior synonyms of the

Figure 9. Distribution of the records of fossil and living *Cyprinotus cingalensis* (blue) and the record of living specimens from the UAE (red). (Map produced with AMCHARTS.COM).

Table 1. Preliminary checklist of the non-marine ostracods from the UAE.

Taxon	Age	Reference
Cyprideis torosa (Jones, 1850)	Late Miocene (7 Ma) - Holocene	Mazzini et al., 2013; Gebel et al., 1989; Preston et al., 2015
Cyprideis sp.	Holocene	Gebel et al., 1989 ; Stewart et al., 2011
Candona (*Lineocypris*?) sp.	Holocene	Gebel et al., 1989
Candona sp.	Late Miocene (7 Ma)	Mazzini et al., 2013
Heterocypris salina (Brady, 1868)	Late Miocene (7 Ma), living	Mazzini et al., 2013; this study
Vestalenula cylindrica (Straub, 1952)	Late Miocene (7 Ma)	Mazzini et al., 2013
Prolimnocythere sp.	Late Miocene (7 Ma)	Mazzini et al., 2013
Cyprinotus cingalensis Brady, 1886	living	this study

species (Brady, 1886; Sars, 1889; Vavra, 1906; Klie, 1933; Sohn and Morris, 1963; Hartmann, 1964; Bhatia and Khosla, 1967, 1975; Malz, 1976; Neale, 1979; Bhatia, 1983; Kempf, 1986; Bhatia and Singh, 1988; Reeves, 2004; Karanovic, 2008, 2012; Mischke et al., 2012; Mohammed et al., 2014) (Fig. 9). *Cyprinotus cingalensis* is apparently distributed in the African and Australasian subtropical and tropical region. Living specimens of *C. cingalensis* or eggs were probably introduced to the AWWR Lake by migrating birds. Specimens or eggs may have travelled attached to the feathers or may have survived passage through the digestive tract (Meisch, 2000; Karanovic, 2012). However, it remains speculative whether the *C. cingalensis* population in the AWWR Lake possibly originates from specimens or eggs of southern origin (Saudi Arabia or Yemen) or from other regions with known or even unknown *C. cingalensis* populations.

The record of *H. salina* from the AWWR Lake is the first record of living ostracods from the UAE. Fossil valves of late Miocene age (7 million years) were reported from the Al Gharbia region in the UAE (Mazzini et al., 2013) (Table 1). The species is widely distributed in the Holarctic region and occurs also in the southern hemisphere where it was probably introduced relatively recently (Meisch, 2000). *Heterocypris salina* is common in the region with records from Iran, Jordan, Palestine, Saudi Arabia and Sudan (Schöning, 1996; Griffiths et al., 2001; Rosenberg et al., 2011; Mischke et al., 2012).

AWWR Lake experienced large fluctuations with respect to water depth, salinity, pH and the other recorded parameters over the monitoring period. The large fluctuations probably result from the discharge of treated waste water at relatively irregular time intervals and the rise of the groundwater level as a results of stronger winds and higher tides in winter which is sometimes accompanied by precipitation. Although generally a very shallow lake, water depth was changing by a maximum of 2.1 m at ST 04. The smallest water depth variations were recorded at ST 10 where depth varied between 0.17 and 0.73 m. The salinity gradient in the lake is extremely large, with a lowest value of 1.45‰ measured at inlet I and a maximum of 457‰ at ST 07. This recorded maximum salinity is significantly higher than those of the Dead Sea brine (~340‰) and even higher than those of the most saline lakes in the Dry Valleys of Antarctica (Marion, 1997). Fluctuations were also most extreme at ST 07 where the salinity changed over a full order of magnitude (from 43‰ in October 2010 to 459‰ in June 2016). In contrast, lowest salinity variations occurred at ST 08 (2.18-68.78‰). However, mostly low salinities of <5‰ were measured at the inlets I and II, and between 5-10‰ at ST 08. The pH values varied from neutral to highly alkaline conditions. Lowest pH values were recorded at the Inlets (mean pH 7.5) whilst predominantly high values occurred at ST 08 (mean pH 8.2).

The concentration of Nitrate in the water of the AWWR Lake is mostly between 5 and 50 mg L^{-1}. These values are typical for treated waters or generally for waters affected by industrial or agricultural activities. However, the nitrate concentrations are mostly not critical with respect to drinking water standards (WHO, 2011; Saji et al., 2016). Similarly to nitrate concentrations, nitrite levels are mostly under the recommended concentration of 3 mg L^{-1} in drinking water (WHO, 2011). Mean ammonia concentrations are between 1.5 mg L^{-1} at inlet I and 2.8 mg L^{-1} at ST 04. These values are relatively high and typical for anaerobic ground waters (WHO, 2011). The Phosphate concentrations in AWWR lake waters are almost exclusively above those of natural waters with geogenic phosphate concentrations of typically <0.05 mg L^{-1}. However, mean concentrations between 2.7 mg L^{-1} at sampling station ST 07 and 8.8 mg L^{-1} at inlet II are not critically high. TOC values are low for the inlets (inlet I: 6.1 mg L^{-1} on average, Inlet II: 7.0 mg L^{-1} on average) and at ST 08 (13.0 mg L^{-1} on average), and between 25.9-54.4 mg L^{-1} on average at the other sampling stations.

Cadmium concentrations are mostly below detection limit (<0.0005 mg L^{-1}) and thus, below the recommended threshold for drinking water of 0.003 mg L^{-1} (WHO, 2011). However, concentrations as high as an order of magnitude above this level were occasionally recorded during the first two years of the monitoring period. Copper concentrations are mostly well below the recommended value of 2 mg L^{-1} (WHO 2011). Iron concentrations in the water samples from AWWR Lake are mostly in the range of naturally occurring waters with the exception of water collected in May 2010.

The results of our study demonstrate that salinity level at sampling station ST08 was significantly lower as compared to other sampling stations at different locations in AWWR. Therefore, the occurrence of ostracods in AWWR Lake is apparently predominantly controlled by salinity level. On the other hand, the evaluation of other parameters at all sampling stations such as pH, TOC and cadmium concentrations did not reveal significant relationships with the distribution of the recorded ostracods. The presence of the recorded ostracods is mainly controlled by the relatively low salinity at station ST08 in AWWR.

Based on our limnological analyses carried out in the years 2010 to 2016, the ostracod species *C. cingalensis* was recorded for the first time in UAE. A second species *H. salina* was also recorded, which was reported from the late Miocene of the UAE before. *Cyprinotus cingalensis* was not recorded for the country before. The ostracods were only recorded at one of nine regularly monitored sampling stations in the lake which is characterised by the lowest salinity of all stations. Thus, salinity is probably the predominant parameter which controls the distribution of ostracods in AWWR Lake. Ostracods were only recorded in a range of relatively low salinities between 2.18-13.74‰.

Future monitoring of the lake would benefit from additional analysis of the bottom-water oxygenation at the stations, from analysis of the ion chemistry of the lake water and of groundwater in the region, and from observations of the temporal occurrence of the individual ostracod species in the lake.

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