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Water quality and brine shrimp (*Artemia* sp.) population in Al Wathba Lake, Al Wathba Wetland Reserve, Abu Dhabi Emirate, UAE

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Al Wathba Lake is located at Al Wathba Wetland Reserve which is located 40 km east of Abu Dhabi Island on the left side of the truck road to Al Ain. The water body extends for approximately 1.5 km in length and 0.5 km in width with a maximum depth of almost two meters (in the period of 2010). Al Wathba Reserve exists primarily because it is supplied with tertiary treated waste water from the Mafraq Waste Water Treatment Plant (WWT). The salinity of the water throughout the lake is variable due to the fresh water input and the underlying Sabkha substrate. The maximum salinity recorded in the lake is 230 ppt although typically the salinity is around 180 ppt. Over the period of February 2010 to December 2010, monitoring programme was carried out with the purpose of understanding the population dynamics, ecology and habitat requirements of the brine shrimp (*Artemia* sp.) at Al Wathba Lake which is the main food source for greater flamingo (*Phoenicopterus roseus*) in the reserve. Nine fixed sampling locations, distributed all over the entire lake's area and two inlet samples were sampled monthly at day time to determine water temperature, salinity, pH, dissolved oxygen, nitrite, nitrate, ammonia, phosphate, total organic carbon (TOC), copper, cadmium and iron. The monthly average of total number of Artemia numbers counted in the sample was between 1.3 and 115 individuals/L but varied significantly between months. For the period considered, cysts were noted to be more abundant than the adults.

Key words: Water quality, brine shrimp, population, Al Wathba wetland reserve, physical parameters, chemical parameters.

INTRODUCTION

In the United Arab Emirates, during 1982, an unplanned discharge of water from a wastewater treatment plant onto an adjacent area of Sabkha led to the formation of a lake, 40 km east to Abu Dhabi Island (Brown, 1983; Aspinall and Hirschfeld, 1993). Subsequent small discharges maintained the lake as a permanent body of water and attracted a variety of wildlife to the area. The permanent water body of the lake attracted many species of birds that became resident on the site. In 1993, a population of greater flamingos (*Phoenicopterus roseus*) became resident in the site and attempted to breed for the first time in the Arabia in over 75 years (Aspinall and Hellyer, 1999). With the view of promoting continued occupation and breeding at the reserve by this regionally important flagship species, the availability of sufficient food resources was identified to be of prime importance.

Al Wathba Lake in Al Wathba wetland reserve is a significant area for conservation and management as it is

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a home for many water birds and especially the flagship species, the greater flamingo (*P. roseus*) (Al Dhaheri, 2004). The brine shrimp (*Artemia* sp.) is the main food resource for the greater flamingo. Brine shrimp have been known to man for centuries, and have been found to be a good food source for newly hatched fish as well as birds (Van Stappen, 1996). The brine shrimp, *Artemia* sp. belongs to the phylum Arthropoda, class *Crustacea*, and were first recorded in 1755 (Kuenen et al., 1938). Brine shrimp is globally distributed in hypersaline biotopes including salt lakes, coastal lagoons and solar salt works (Vanhaecke et al., 1987; Tackaert et al., 1993). The diversification of Artemia habitat varies in terms of anionic composition, climatic conditions and altitude. Depending on the prevailing anions, Artemia may inhabit chloride, sulphate or carbonate waters and a combination of two or even three major anions (Bowen et al., 1985; Browne., 1988). In general, Artemia are found in all continents throughout tropical, subtropical and temperate climatic zones, except Antartica (Triantaphyllids et al., 1995). The distribution of *Artemia franciscana* in the Americas may largely be attributed to the dispersal by birds where *Artemia* biotopes are known to be feeding grounds for many birds and especially flamingos (Rooth, 1976). Furthermore, the migration route of these birds had played an important role in dispersing *Artemia* over large distances. Brine shrimps are parthenogenetic with the exception of one *Artemia urmania* population in Iran. There are many problems in recognizing the species designation of a newly discovered brine shrimp population. There may be two populations in the same saline habitat. For example mixtures of parthenogenesis and biparental populations have been reported in Mediterranean salterns (Van Stappen, 1996).

The life cycle of *Artemia* begins from either a dormant cyst that is extremely hard and may remain viable for few years or an ovoviviparous egg which hatches immediately. During periods of low salinity and temperature, the cysts begin to rehydrate and open to release the stage larva which is known as first naplius larva. The larva remain in this stage for about 12 h, feeding on the yolk sac before moulting to a second instars known as the metanaupliar stage, which remain until the sixth moult when they are termed postmetanauplii; following the 12th moult they are termed post-larval and by 17th moult they are regarded as adult. From the second instar onwards, they are able to feed on small algal cells; by the time they reach an adult size of 10 mm length, they are able to feed on large conglomerates of algae.

Under optimum conditions of food supply and lack of stress due to increased salinity or decreased dissolved oxygen, the female shrimp may produce eggs. These eggs will hatch after being released from the ovisac to produce nauplius larvae. The female shrimp can live for up to 3 months and produce up to 300 nauplii every four days after such optimum conditions.

An *Artemia* programme was developed by the Terrestrial Environment Research Centre of Environment Agency- Abu Dhabi ((TERC, EAD) in the year 2001. The aim of the programme is to provide a guideline for the management of the water body to facilitate maximal brine shrimp production to ensure the continuous availability of food source for greater flamingo (Al Dhaheri and Drew, 2003; Al Dhaheri, 2004; Tourenq et al., 2004).

MATERIALS AND METHODS

Study area and sampling

Al Wathba is an inland wetland occupying 4.9 km^2. It houses a breeding colony of the greater flamingo (*P. roseus*). Al Wathba wetland reserve is located 40 km east of Abu Dhabi Island on the left side of the truck road to Al Ain. The water body extends for approximately 1.5 km in length and 0.5 km in width to a maximum depth of almost two meters. Al Dhaheri (2004) showed that there were no difference in monthly trends of individuals and *Artemia* cysts between surface-water samples and near-bottom samples. The effects of date of sampling, the site location of sampling, and their interaction on physical-chemical parameters (Camargo et al., 2004) our Artemia were examined using a generalized linear model (GLM) approach.

The sampling sites for *Artemia* monitoring were chosen on a 100 m grid overlaid on a geo-corrected digital satellite image of the Al Wathba Wetland Reserve (Al Dhaheri, 2004). Altogether, 9 sampling locations have been selected on the basis of their representation of the physical-chemical characteristics of Al Wathba waters (Table 1 and Figure 1), in addition to these 9 sampling sites of the lake, water samples from two fresh water inlet valves have been included to understand the water quality of tertiary treated water from Al Mafraq Sewage Treatment Plant. Samples collection was carried out monthly at day time. During each sampling, the horizontal sampling device (Van-dorn water sampler) was deployed for surface sample collection. Temperature, pH (*in situ)* using multimeter sensor (wtw 350i), time of sampling and depth of each sampling site was also documented.

As in Al Wathba Lake, the discharge of the standing water in the lake was supplemented by brackish water from the Al Wathba Camel Race Track and continued discharge from the Wastewater Treatment Plant. Heavy metals can enter a water supply by industrial and consumer waste, especially from treatment plants. A set of water samples from all sites collected for analyzing chemical parameters such as pH (test method APHA 4500 H+), salinity (test method APHA2520 (B), dissolved O_2, nitrate (NO_3), nitrite (NO_2), phosphate (PO_4), ammonia (NH_3), total organic carbon (TOC), copper (Cu), cadmium (Cd), and iron (Fe). All chemical analysis was conducted at the laboratories of Arab Centre for Engineering studies, Abu Dhabi, UAE (ACES). In the current paper, only the physical parameters were considered for its impact on the *Artemia* population. Previous study showed that *Artemia* population inhabiting Al Wathba Lake is mostly affected by water temperature, water salinity and water pH (Al Dhaheri, 2004).

Counting of *Artemia*

Artemia were counted on a grid under stero-microscope after filtration of the water samples with plankton mesh sized 20 µm and euthanized with sparkling water (*Artemia* are killed by the CO_2 contained in sparkling water). Cyst density was calculated in 1 L of

Table 1. Artemia monitoring programme water sampling points.

Sites	Latitudes	Longitudes
ST01	24.255088	54.607143
ST02	24.256866	54.604163
ST03	24.259169	54.601224
ST04	24.25919	54.598119
ST05	24.262745	54.596097
ST06	24.261611	54.59825
ST07	24.262282	54.590102
ST08	24.259721	54.611577
ST09	24.262707	54.609447
ST10	24.259374	54.604496
Inlet water Valve- I	24.26384	54.59609
Inlet water Valve- II	24.26425	54.6051

Figure 1. Map of Al Wathba with location of sampling sites.

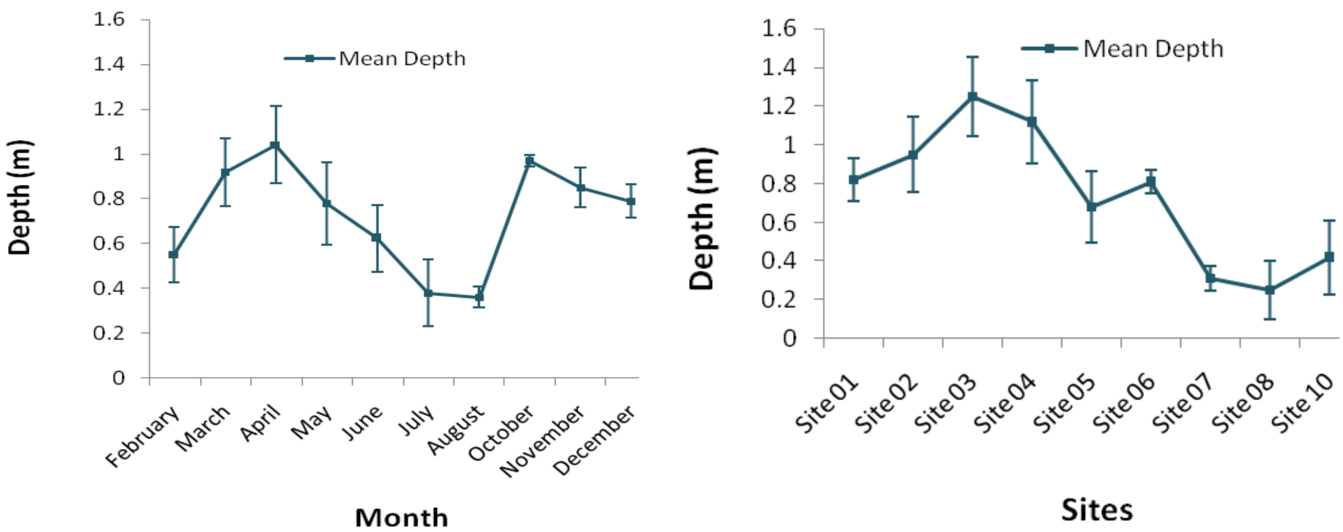

Figure 2. Annual mean depth recorded during sampling.

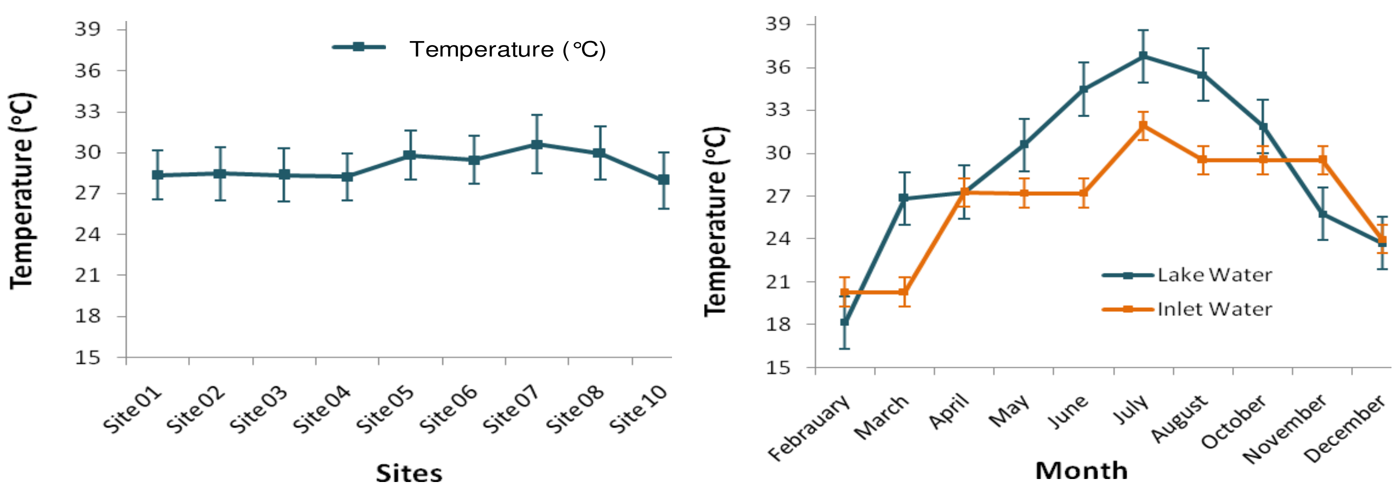

Figure 3. Variation of mean (± SE) temperatures of surface water and inlet water.

the sample (total cyst/1 L = ((total cyst/6ml) x 1000) (Al Dhaheri, 2004). We compared physical-chemical parameters and *Artemia* numbers between dates and sampling sites using one-way analyses of variance, ANOVA (Sokal and Rohlf, 1997) and also detected the correlation between water conditions and *Artemia* occurrence in sampling locations during the period considered.

RESULTS

Physical-chemical parameters of samples

The general average depth of the lake at 9 sampling points was 0.74 m (±0.12 SE). Deepest water level was recorded at Site 03 and lowest water level at Site 08 (Figure 2). Water levels of the lake showed a decrease during the month of August and it increased in the month of April.

Temperature

The average surface temperature of the lake was around 29°C during the entire year, and varied from 18 (February) to 36°C (July) (Figure 3). Temperatures of water samples were not different according the site location of sampling (Figure 3). The average temperature of the inlet water showed same pattern and fluctuated around 26°C varying from 20 (February) to 32°C (July – November) during the period considered.

Salinity

The salinity varied among the sites and ranged between

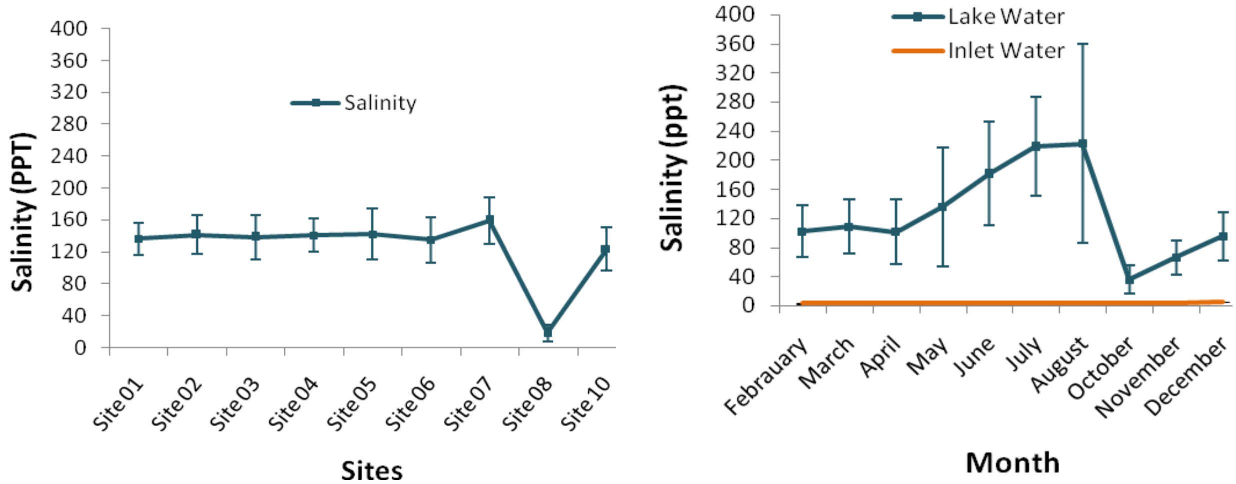

Figure 4. Variation of mean (± SE) salinity of surface water.

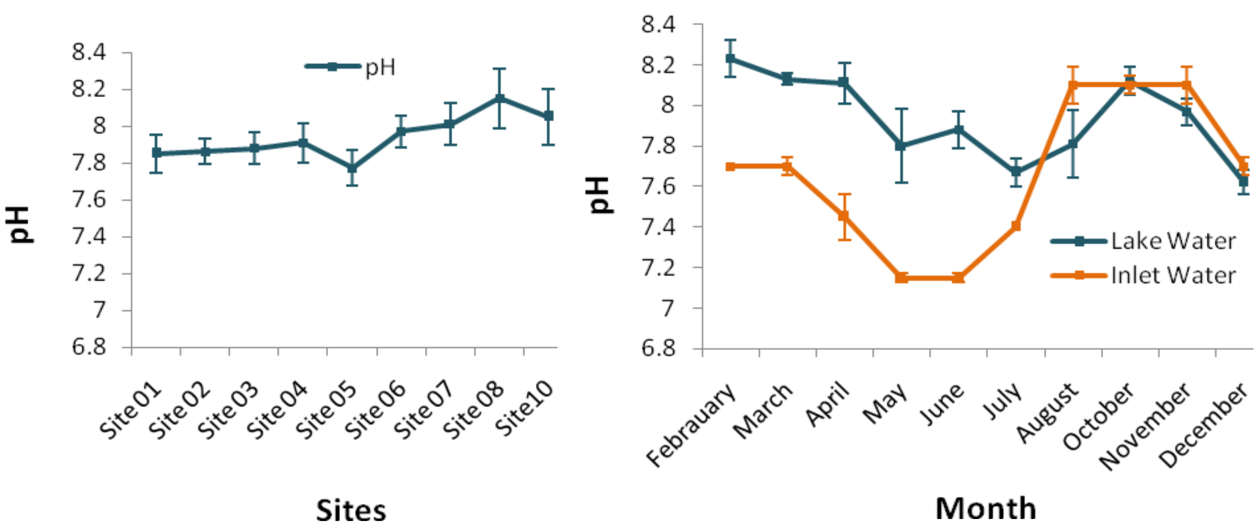

Figure 5. Variation of mean (± SE) pH of surface water and inlet water.

18.34 to 159.33 ppt and found to be not significant (ANOVA test, F = 8.4, df 9, p = >0.05) for all the period considered (Figure 4). The mean salinity of the lake fluctuated around 126 with a minimum of 35 ppt and a maximum of 222 ppt in October and August, respectively, with Site 08 having the lowest salinity with 18.3 ppt and Site 07 having highest salinity for the whole period. The average salinities of inlet water samples fluctuated around 2.8 and 4.5 ppt as minimum and maximum was recorded in July and December.

pH

The mean pH was significantly different between months and fluctuated around 8 (ANOVA test F = 4.1, df = 9, p = <0.05) (Figure 5). The minimum pH of the lake water was 7.6 and the maximum was 8.2 for the whole period considered. The average pH of inlet water samples was around 7.6 with a minimum of 7.1 and a maximum of 8.1.

Artemia concentration

The mean monthly total number of *Artemia* (adult, juvenile and cyst) was comprised of between 1.3 and 115.8 individuals/L (Figure 6) but not varied significantly between months (ANOVA test, F = 2.249, df 2, p = >0.05). The mean *Artemia* number ranged between 0.63 and 215 individuals/L according to the site and the lowest

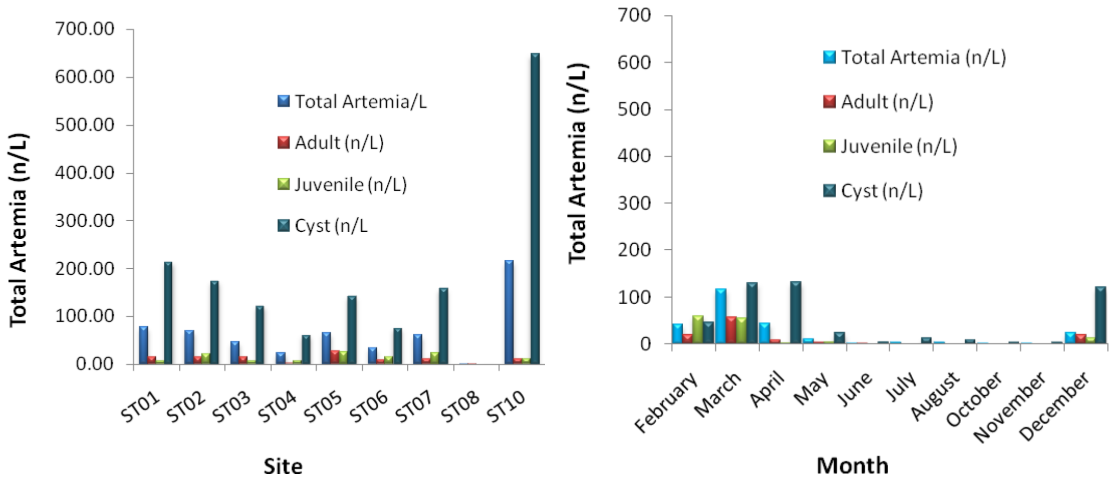

Figure 6. The mean monthly total number of *Artemia* population, *Artemia* adult, juvenile and cyst in Al Wathba Lake surface water.

concentrations were found in Site 08 and highest concentrations in Site 10.

Adults

The mean monthly total number of adult *Artemia* was comprised of 0.1 to 26 individuals/L but did not vary significantly between months (ANOVA test F = 7.9, df 9, p = >0.05). However, a decline trend was observed in July, August and October. During the period considered, Site 08 had a lower adult concentration and maximum concentration in Site 01 (Figure 6). The presence of adults *Artemia* in water samples was more linked with the sampling sites. Salinity is shown to be strongly correlated with the occurrence of adults in the sampling sites.

Juveniles

The mean monthly total number of juvenile *Artemia* was comprised of between 0 and 59 individuals/L (Figure 6) but did not vary significantly between months (ANOVA test F = 6.16, df = 9, P = >0.05). The total number of juveniles showed increase between the February, March and December. However, a decline was observed in June, July, August, October and November. Site 05 and Site 07 tended to have more juveniles than other sites. A strong correlation exists between the parameters (pH and salinity) and the juvenile development. pH is strongly correlated to the occurrence of juveniles for the period considered and salinity is related to the juvenile production in sampling sites.

Cysts

The mean monthly total number of cyst *Artemia* was comprised of between 1 and 647 individuals/L but did not vary between months (ANOVA test F = 6.82, df = 9 P = >0.05) and is not statically significant for the whole period considered. The total number of cysts showed increase in March and April. However, a decline was observed in June, July, August, October and November. Site 10 tended to have more cysts than other sites and Site 08 had the lowest number observed (Figure 6). No relationship could be established between the parameters (depth, temperature and pH) and cyst production for the nine locations sampled. Further, the parameters (depth and pH) were shown to be correlated to cyst production during the period considered for the study.

Composition of the *Artemia* population in Al Wathba

For the period considered, cysts were more abundant than adults (Table 2). Cyst constituted 66%, larvae 20% and adult 14% of the total composition. Mortality rate of adults and juvenile *Artemia* in Al Wathba Lake surface water samples has not been considered for the study. The ratios of juvenile/adults or cysts/adults were found to be significant for the whole period considered (ANOVA test F = 7.255, df = 2, P = <0.05). Excluding Site 08 where no adults were observed, these ratios were statistically different between locations. However, a tendency of decline in the number of juveniles was observed from June to October and in the adults in July, August and October.

Correlation between water conditions and *Artemia* occurrence in Al Wathba Lake

To summarize the results, we were able to show a

Table 2. Monthly proportions of adults, juveniles and cysts on the total number of individuals in Al Wathba Lake surface water samples.

Month	Adults (%)	Larvae (%)	Cysts (%)
February	16	48	36
March	16	20	64
April	7	2	91
May	13	15	72
June	33	0	67
July	0	0	100
August	0	0	100
October	0	0	100
November	10	5	85
December	14	20	66

relationship between the physical parameters (depth, temperature, pH and salinity) and *Artemia* occurrence. Depth and pH were shown to be correlated to *Artemia* during the period considered. No parameters except salinity have correlation between *Artemia* occurrences in sampling locations.

DISCUSSION

Al Dhaheri (2004) showed that optimum conditions for *Artemia* production were when salinity was around 75 ppt, pH 8 and surface water temperatures ranging between 25 and 30°C. The optimum pH for *Artemia* growth ranges from 8.0 to 8.5 (Vos, 1979) and cyst hatching efficiency was greatly compromised at pH below 8.0 (Sato, 1967). For all months considered, surface water temperature of the lake remained between 18.18 and 36.75°C, average pH of 7.9 and average salinity of 126.75 ppt. In the inlet water samples, temperature was 20.3 to 31.9°C, average pH was 7.6 and average salinity was 3.3 ppt. Therefore, during the study period considered in 2010, the physical conditions stood within the range of normal conditions for the survival of *Artemia* as it was reported that they can tolerate salinities up to 237 ppt (Al Dhaheri, 2004).

The lowest number of adults was found in Site 08, close to sewage treatment plant output which had the lowest salinity (18 ppt). The average monthly number of cysts did not vary significantly during the period considered. At all the sites considered, juveniles were abundant more than adults. Overall, Al Wathba lake water quality during the period considered in 2010 (physical and chemical) remained within the optimum conditions for the survival and reproduction of *Artemia* and suitable for cysts hatching.

The concentration of *Artemia* varied according to the date and the location of the sampling site. Over the whole period considered, the mean monthly total number of *Artemia* ranged between 0 and 57 individuals/L, and 0.1 to 26 individuals/L according to the site. Given that *Artemia* concentration depend on several factors, such as nutrients (Jellison and Lelack, 2001) concentration and physical-chemical parameters, our *Artemia* values ranged within the values found elsewhere in the world (Tourenq et al., 2004). For the period considered, an average *Artemia* concentration of 65.8 individuals per liter (ranging between 0.6 and 215) according to the sampling site was found. Rooth (1965) and Johnson (1983) stated that flamingo's food requirements are 10% of its body weight per day. This equates to a daily requirement of 225 to 340 g or 135,000 *Artemia* per day. According to the current data, the total quantity of *Artemia* in the lake is 98867197800 individuals, a quantity that could theoretically feed up to 732350 flamingos per day (range of 6678 to 2392935 according to the site) which means that the site could support 1 flamingo per 732350 days or 732350 flamingos per one day. The breeding season of flamingos is about 4 months (120 days), from nesting to chick fledging (Johnson, 1983). Al Wathba lake could thus theoretically support (732350/120) 6103 flamingos per day or 3051 pairs per day. Therefore, for the period considered, the carrying capacity of lake seems higher than the current population of flamingos visiting the lake (average of ca 3,387 individuals per count per day for the year 2010) (Ahmed et al., 2010). The results of previous studies on assessment of brine shrimp productivity at Al Wathba lake also showed same results (Tourenq et al., 2004a, b; Saji and Mayyas, 2007).

The input of fresh water is the main parameter that can, and should, be controlled at the lake. Controlling the water input allows a degree of control over water salinity. The right amount of water input during winter and summer is vital to ensure the optimum salinity for cyst hatching and subsequent population development. Water level in summer is one of the key factors ensuring maximum breeding of *Artemia*. If water level is low, temperature and salinity will increase and cyst will be formed. Following this, at the beginning of winter when the ambient temperature has fallen, fresh water can be put into the lake. This will trigger the hatching of cysts and the lake body will be at the optimum salinity and temperature for maximum reproductive rate within the *Artemia* population. The water quality and *Artemia* monitoring programme is important to produce guidelines on the management of the water body and ensure the maximum brine production and there by sustainability of greater flamingo (*P. roseus*) at Al Wathba wetland reserve in the Emirate of Abu Dhabi. Monitoring of physical-chemical and *Artemia* concentration would be able to compare values between years. *Artemia* concentration values are less than the range of values found in Al Wathba Lake in the previous studies (0.07 to 30.4- Al Dhaheri, 2004), (0.2 to 32– Tourenq et al., 2004), (0.2 to 47- Saji and Mayas, 2007). So, the study provides a unique data set on an aquatic ecosystem in the United Arab Emirates and the Gulf region.

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