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Assessment of Brine Shrimp (Artemia sp.) Productivity at Al Wathba Wetland Reserve, Abu Dhabi (UAE)

Shaikha Salem Obaid Al Dhaheri

United Arab Emirates University
Deanship of Graduate Studies
M.sc. Programme of Environmental Sciences

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By
Shaikha Salem Obaid Al Dhaheri
B.Sc. in Nutrition and Food Science
Faculty of Agricultural Sciences, U.A.E University (2000)

Supervised by

Dr. Waleed Hamza Chairman of Biology Dept. UAE University	Prof. Abdel-fattah El-Sayed College of Food Science UAE University	Dr. Richard Perry Senior Researcher ERWDA

UAE University
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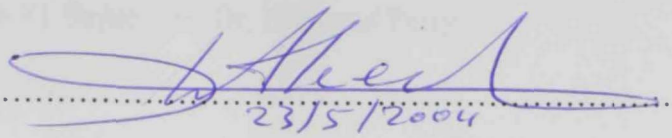
The Thesis of Sheikha Salem Obeid Al Dhaheri for the Degree of Master of Science in Environmental is approved.



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Examining Committee Member, Dr. Waleed Hamza

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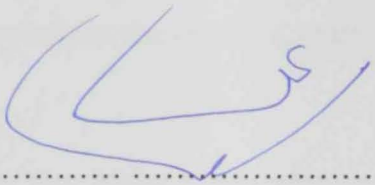
Examining Committee Member, Dr. Andrea Lami



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Examining Committee Member, Dr. Sofian Alian

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Dean of the Graduate Studies, Dr. Hadef Rashed Al-Owais

United Arab Emirates University
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Abstract

Abstract

Al Wathba Lake was created in 1982 by accidental discharge of over-capacity treated sewage water from Al Mafraq Waste Water Treatment Plant (WWT). The lake lies on the north side of the Abu Dhabi – Al Ain truck road, approximately 40 km Southeast of Abu Dhabi Island. In 1998, the lake and its surroundings were designated as protected area, the Al Wathba Wetland Reserve, and placed under the management of the Environmental Research and Wildlife Development Agency (ERWDA). The reserve covers an area of approximately 5 km^2, and the lake system covers an area of 1.5 km^2. The continued inputs of water and high evaporation rates have resulted in fluctuating water salinity of the lake from fresh to hyper-saline. The reserve attracts large numbers of migrating waterfowl and waders including the greater flamingos (*Phoenicopterus ruber*) which is the only known currently breeding colony in the Arabian Peninsula. Brine shrimp (*Artemia* sp.), the only crustaceans inhabiting the lake, are the main food source for the flamingos. Brine shrimp can tolerate a wide range of water quality conditions, particularly water salinity variations. However, little information is available on the effects of water quality on *Artemia* populations inhabiting Al Wathba Lake. Considering the potential importance of brine shrimp as a food source for the flamingos population, and the government interest to conserve the established population, the present study was carried out to examine the dynamics of brine shrimp population in relation to the surrounding environment. The second goal of the study has also aimed to develop a management plan for the lake environment, in order to guarantee continuous reproduction of *Artemia* population and consequently the conservation of the established flamingos population.

In the framework of the present study, a total of 14 sampling sites were investigated on a monthly basis form April 2002 to January 2003. At each site, water samples were collected from both surface and near-bottom levels and in case of sampling sites that are less than 50cm in depth, only surface sample was collected. Water temperature, salinity and pH were measured *in situ* using a multi meter hydrolab device. The collected water samples were analysed in the laboratory to determine the surface and near-bottom concentrations of nitrite, nitrate, phosphate, ammonia, magnesium and calcium for each sampling site. Moreover, the density of *Artemia* organisms and their cysts numbers were counted for each site.

In order to evaluate the tolerance of *Artemia* organisms to the variations in the lake environment, *Artemia* specimens were collected from Al Wathba Lake and tested for the following variables: a- water temperature (15o, 25o, 30o, 40oC), b- water pH (7.5, 8, 9.5, 10), c- water salinity (75, 100, 150, 200 ppt) and d- food types (*Duluniella, Chlorella, Tetraselimus sp.*, yeast). These tests were run for three weeks until the last individual died, and the optimum survival rates were detected. In addition, *Artemia* specimens were sent to the Laboratory of Aquaculture and *Artemia* Reference Centre in Belgium for taxonomic identification. From the preliminary investigation, the centre has identified the given specimens as ***Artemia franciscana.***

Results from the collected field data revealed that the *Artemia* population inhabiting Al Wathba Lake is mostly affected by water temperature and water salinity. *Artemia* was absent during the summer months due to the high water temperature (maximum= 34.5 °C) and salinity (maximum= 237.5 ppt). In winter, *Artemia* was abundant in the lake when water temperature was 18.6 °C and water salinity was

dropped off to 70.4 ppt. The statistical analysis of the studied parameters showed that the chemical composition of the lake water had no significant effect on the presence or absence of *Artemia* in the lake.

The laboratory experiment showed that *Artemia sp.* was greatly influenced by water salinity and water pH. It was found that *Artemia* population inhabiting Al Wathba Lake maintains better performance at salinity of 75 ppt and a pH of 8, and the survival was longer than the other combinations. In addition, it was found that the optimum temperature at which the best performance and longest survival were recorded of all between 25-30 °C.

According to the preliminary identification of the *Artemia* species, and in light of the field and laboratory results, it seems that the existing *Artemia* species at Al Wathba Lake may match the *A. franciscana* behavior. However, the response to other environmental parameters did not match that of *A. franciscana* features. Therefore, further genome analysis is suggested in order to identify the specific taxonomic rank of the *Artemia* population in Al Wathba Lake.

Introduction

Introduction

According to the Ramsar Convention, wetlands are defined as areas of marsh, fen, peat-land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt (Article 1.1, Ramser Convention, 1996). In addition, they could be human-made wetlands, such as shrimp ponds, farm ponds, irrigated agricultural land, salt pans, reservoirs, gravel pits, sewage ponds and canals. It is widely known that, wetlands and salt lakes sustain a huge diversity of life and perform essential functions in the maintenance of ecological balance. Interfacing between land and water systems had made them highly productive, biologically rich, and also endangered (Barbier *et.al.*, 1997; Ramchandra, 2001). In fact, wetlands have been described as "the kidneys of the landscape", because of the functions they perform in the hydrological and chemical cycles (Mitch *et. al.*, 1993).

Both fresh water and saline lakes have a large number of uses and values. A major economic use of fresh water lakes and reservoirs is as a source of fresh water for irrigation. Other uses include: domestic usage, industrial usage and generation of electricity. Saline lakes are also useful as a source of minerals, fine biochemicals and as a source of food for maintaining saline species for aquaculture; especially *Artemia* sp. (Williams, 2000). Because of this diversity in biological and physical attributes, wetlands have attracted the attention of ecologists, physiologists, biochemists, geochemists, palaeolimnologists and others. Moreover, the educational value of wetlands should not be underestimated. As environmental issues become increasingly important, and as global climatic and atmospheric changes take effect, they provide important examples of natural environmental systems to demonstrate the importance of maintaining sustainable ecosystems.

Many lakes inspire spiritual emotions and feature prominently in religious writings; also, many recreational activities take place on or near by. They may be used for 'wind-surfing', speed trials, and lake mud could also be used for therapeutic purposes as, for example, in the Dead Sea (Williams, 2000).

Saline lakes and wetlands are found on all the Earths' continents except the Antarctic. In 1933, it has been estimated that, North America had more than 200 natural and constructed wetlands (Knight *et al.*, 1993), and Europe had more than 500 subsurface flow wetlands (Brix, 1993). As for dryland lakes, the world's largest lake, the Caspian Sea (374000km2), occurs in an arid environment, in addition to several other lakes of areas greater than 10000km2 (Aral sea, Chad lake, Balkhash, Eyre and Torrens lake) (Herdendorf, 1990).

In Arab lands, apart from ephemeral salt lakes that occur after rains on lowlying areas with hyper-saline substrate (sabkha), several extremely large reservoirs have been built in drylands, including the Aswan High Dam in Egypt and Sudan and the Razza Dyke in Iraq (William, 2000). The rapid urban and agricultural development in the Arabian Peninsula has also resulted in the creation of artificial wetlands which are either water storage reservoirs, areas of spillage from irrigation systems, sewage treatment ponds or artificial lagoons created by waste water from urban and industrial areas (Dugan, 1993). In the Gulf region, there are no known permanent saline lakes with year-round standing water, only ephemeral lakes that form after rains on sabkha. However, a number of large artificial wetlands known to

exist such as the reservoirs in Wadi Hanifah and Wadi Jizah in Suadia Arabia which supports several thousands of waterfowl during winter season (Dugan, 1993).

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 *et. al.*, 1993). Subsequent small discharges maintained the lake as a permanent body of water and attracted a variety of wildlife to the area. In 1998, the lake and its surroundings were designated as a protected area, known as the Al Wathba Wetland Reserve, and placed under the management of the Environmental Research and Wildlife Development Agency (ERWDA).

The reserve covers an area of approximately 5 km^2, while the lake itself covers an area of 1.5 km^2. The reserve supports a wide biological diversity of birds, small mammals, plants and invertebrates. The permanent water body of the lake attracted many species of birds that became resident on the site, such as Black-winged stilts and Kentish plovers. It also made a good stop station for migrating birds such as the greater flamingo. In 1993, a population of greater flamingo (*Phoenicopterus ruber*) became resident in the site and attempted to breed for the first time in the Arabia in over 75 years (Aspinall & Erik, 1993, Aspinall *et. al.*, 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.

Since the formation of the lake, its water salinity has increased from brackish to saline and lately to hyper-saline. This happened because of the continuous input of salts with water from the sewage treatment plant coupled with leaching from soil substrates and the extremely high rates of transpiration common in the hot, arid climate of Abu Dhabi Emirate. In fact, the high rate of evaporation and the sabkha substrate has led to a situation where the water salinity within the lake now ranges from 50 – 200 ppt. The lake, with its hypersaline nature, has become suitable for the brine shrimp (*Artemia* sp.) development.

Brine shrimp have been known to man for centuries, and have been found to be a good food source for newly hatched fish larvae as well as for birds (Van Stappen, 1996). The present study is the first study on brine shrimp in the UAE. It is also unique in that it focuses mainly on finding the proper way to manage the water body in the reserve. The objectives of the study were to:

1. Assess the *Artemia* population inhabiting Al Wathba Lake.
2. Quantify the lake environmental conditions and the distribution of the brine shrimp population.
3. Understand the relationships between environmental conditions and brine shrimp population dynamics.
4. Design a management program that could maintain the lake conditions favouring the sustainable *Artemia* population as a food source for the greater flamingos.

Site Description

History

Al Ghar is a sabkha area, located 40 km east to Abu Dhabi along the north side of the Al Ain truck road (Fig. 1). This area had been known to become water saturated during the winter months, presumably as a result of sub-surface flow through and hydrostatic back-up during spring high tides (Aspinall *et. al.*, 1999). Subsequent rain and the construction of the road truck to the south formed body of open water, often existing for several months each year.

Following heavy rains in 1989/1990, a substantial amount of water was collected on the northern side of Al Ain truck road. The water body started to attract waterfowl such as Kentish Plover *Charadrius alexandrinus,* Black-winged Stilt *Himantopus himantopus* and Greater flamingoes *Phoenicopterus ruber*.

In 1990, Emirates Natural History group (ENHG) members reported illegal shooting to H.E. Sheikh Nahyan Bin Mubarak Al Nahyan. Shooting was banned in the area and a 24-hour police patrol was initiated. Since the shooting was banned, waterfowl and waders started to return again to the site. In early 1991, about 125 flamingos were recorded, increased to about 650 individuals by the end of the same year (Aspinall & Erik, 1993). In June 1993, flamingos started to colonize and nest on the lake to the south of the truck road, but the breeding failed due to either human or predator disturbance.

After the shooting incidence, and according to the instructions of H.H. Sheikh

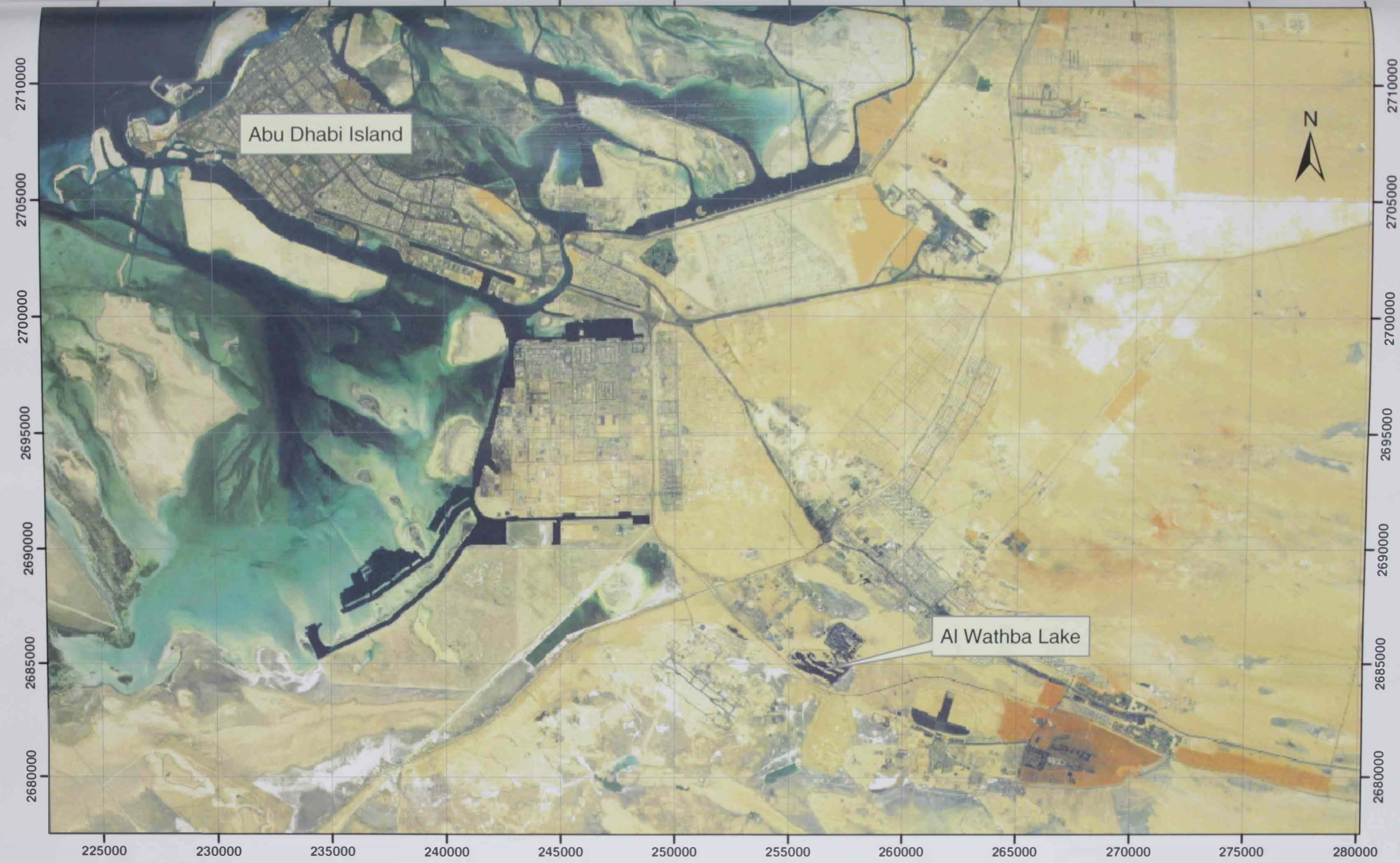

Figure 1 Map showing the location of Al Wathba lake

Zayed Bin Sultan Al Nahyan, the area has been designated as a natural reserve named "Al Wathba Wetland Reserve" and managed by the Environmental Research and Wildlife Development Agency (ERWDA).

In 1999, at least a dozen nests containing eggs were seen by ERWDA staff. Unfortunately, the unplanned release of water from Al Mafraq Waste Water Treatment Plant washed some of the nests away. A few days after the incident, there were still some adult flamingos occupying nests. Ten chicks were recorded in the following week. This instance of successful reproduction by flamingos in 1999 was the first recorded in the Arabian Gulf peninsula in over 75 years (Aspinall *et. al.*, 1999).

Ecology of Al Wathba Reserve

Al Wathba Reserve covers an area of approximately 5 km^2 and the lake body itself covers about 1.5 km^2 (Fig. 2). The reserve consists of several different habitats, including a fresh water lake, saline lakes, tall-reeds marshes, sand dunes and sabkha. This habitat mosaic has attracted a high diversity of fauna to the reserve and has given the site a high priority for conservation.

Around 35 species of native flora have been recorded in the reserve. The dense cover of these plants has created a good habitat for cheesman's gerbils *Gerbillus cheesmani*, brown mouse and the other rodents in the reserve. It has also provided good shelter for desert hares *Lepus capensis*. Therefore, the diversity of the flora such as *Zygophyllum qatarense*, *Haloxylon salicornicum* and *Diptergium glaucum* in the

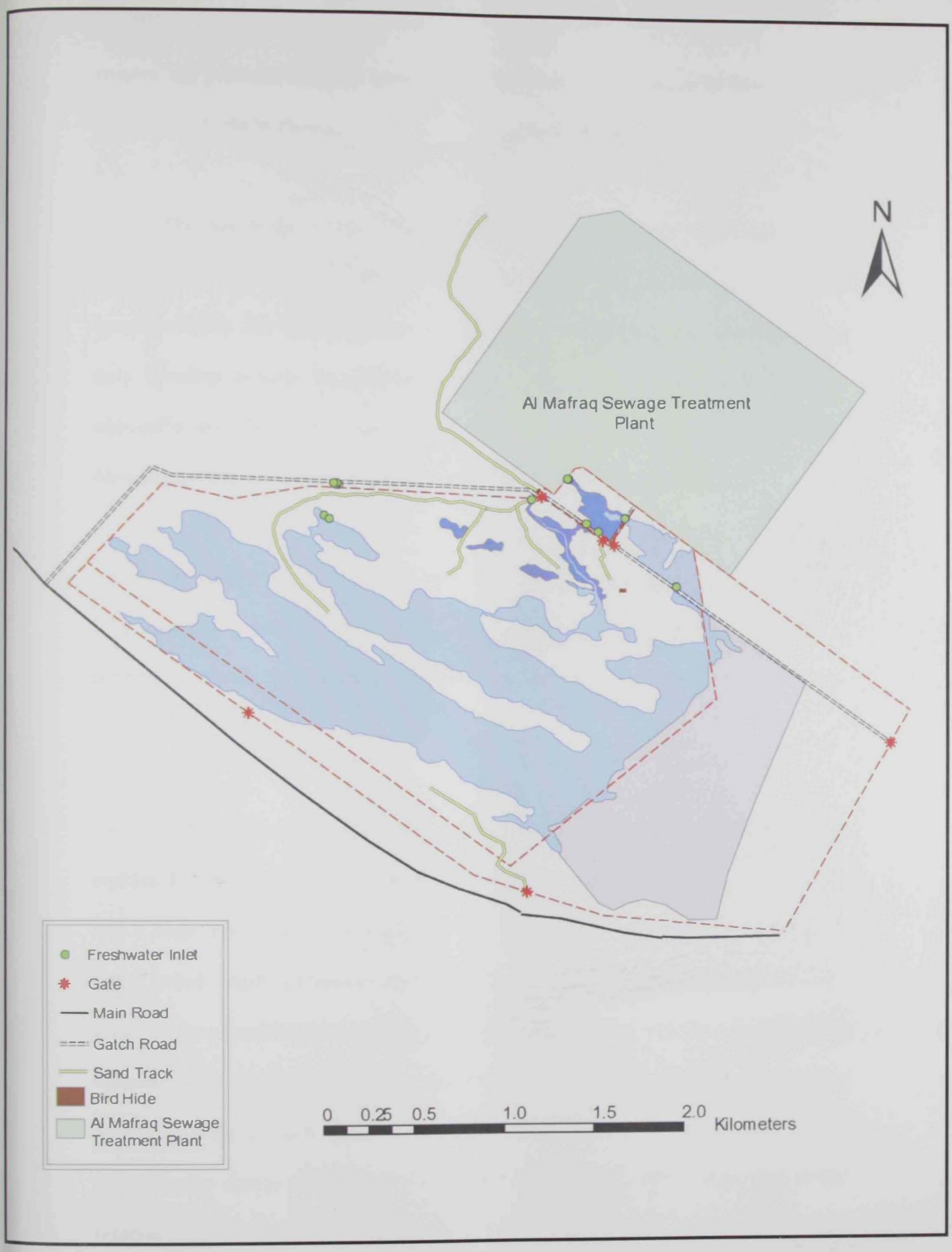

Figure 2 Schematic map showing Al Wathba Wetland Reserve and the Mafraq Sewage Treatment Plant

reserve has provided not only good shelter, but also a good source of food for both rodents and hares in the reserve.

The lake body, which is about 1.5 km long and about 0.5 km wide, with a depth range from a few centimeters up to two meters has attracted more than 200 species of birds. For example, apart from the greater flamingoes, the reserve holds the only breeding avocets *Recurvirostra avosetta* and black-necked grebes *Podiceps nigricollis* and the largest breeding population of black-winged stilt *Himantopus himantopus* and Kentish plovers *Charadrius alexandrinus* in the UAE.

Al Wathba reserve hosts not only birds and small mammals but also a family of at least five red fox *Vulpes vulpes*. Cemented sand barrows and the availability of food in Al Wathba reserve have made it a good place for the red foxes to be present year-round.

The reserve is also characterized by a high diversity of invertebrates and reptiles. Invertebrates such as butterflies, dragonflies, damselflies, wasps, and beetles had a huge distribution in the reserve. The two largest desert reptiles, the "dhub" Spiny tailed lizard *Uromastix microlepis* and the desert monitor lizard *Varanus griseus* have a good burrows habitat which is formed from the cemented sand found at various locations in the reserve. Schmidt's fringe-toed lizard *Acanthodactylus schmiditi*, baluch roch gecko *Bunopus tuberculatus* and dune sand gecko *Stenodactylus doriae* are just a few examples of the reptiles that can be seen in the reserve.

Al Wathba wetland reserve exists only because it is supplied with secondary treated water from Al Mafraq Waste Water Treatment Plant and with saline irrigation run off from Al Wathba Camel Race Track. The requirement for water, in order to counteract the effects of evapo-transpiration, varies from 8,000 m^3 of water per day in winter up to 22,000 m^3 per day in summer (Al Wathba Management Plan, 2001).

The continuous evaporation of the water and the input of the brackish water have caused some parts of the lake to become hyper-saline. This high salinity is thought to be a primary factor making the site suitable for the flourishment of *Artemia* sp., which is known as the only food resource for the Greater Flamingos, and some other bird species.

Literature Review

Brine Shrimp (*Artemia sp.*)

The brine shrimp *Artemia* sp. belongs to the phylum *Arthropoda*, class *Crustacea*, and were first recorded in 1755 (Kuenen *et. al*, 1938). From the second half of the 19th century onward, many studies were published on the morphology and taxonomy of this anostracan crustacean. In the period from 1910 to 1968, the profusion of names was abandoned and most workers referred to all brine shrimps as *A. salina* Linnaeus 1758 (Browne, 1991). Early taxonomist assigned species names to populations with different morphologies, although they were collected at different temperatures and salinities.

It is well known that *Artemia* inhabits hyper-saline environments and has a wide geographical distribution (Persoone & Sorgeloos, 1980; Browne & MacDonald, 1982; Vanhaecke *et. al.*, 1987). Brine shrimp is also globally distributed in hypersaline biotopes including salt lakes, coastal lagoons and solar salt works (Vanhaecke *et. al.* 1987, Tackaert *et.al.*, 1993). In 1915, Abonyi published a list of 80 *Artemia* sites located in 21 different countries. Later on, 28 sites were reported by Stella (1933). Moreover, Persoone & Sorgeloos (1980) included a list of 243 sites distributed over 48 countries. Also, Vanhaecke (1987) provided an updated list of *Artemia* sites resulting from a thorough literature survey and several personal communications received at the *Artemia* Centre in Ghent (Belgium). He provided a list of more than 350 *Artemia* sites including their geographical coordinates.

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; Bowen *et al.*, 1988). It can be found in altitudes as low as sea level to almost 4500m in Tibet (Xin *et al.*, 1994) and in climatological conditions ranging from humid-subhumid to arid (Vanhaecke *et al.*, 1987). In general, *Artemia* are found on all continents throughout tropical, subtropical and temperate climatic zones except Antarctica (Triantaphyllidis, 1995).

Recently, substantial information became available about the existence of *Artemia* in Asia and especially in the People's Repuplic of China (Triantaphyllidis *et. al.*, 1994; Xin *et. al.*, 1994). Despite the efforts made in recent years on new *Artemia* populations, information on the biogeography of this anostracan is still very limited in many Asian, African and East European regions. On the other hand, the history has already proved that brine shrimp populations and biotopes might disappear not only as a result of human intervention, but also due to natural causes such as temporal climate changes (Vanhaecke *et. al.*, 1987).

As pointed out by Browne & MacDonald (1982), the brine shrimp that exist in the Americas is exclusively sexual. With the exception of the geographically isolated *Artemia persimilis* in Argentina, all *Artemia* in the Americas belong to the *Artemia franciscana*. 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. On the other hand, all Asian brine shrimps are parthenogenetic with the exception of one *Artemia urmiana* population in Iran (Lenz *et. al*, 1991, Van Stappen *et. al.*, 2001). In Europe, Africa and Australia both parthenogenetic and

bisexual forms occur (Browne & MacDonald, 1982; Vanhaecke, 1987; Browne & Bowen, 1991). 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).

Economic and Nutritional Value of Brine Shrimp

Although *Artemia* has been known to man for centuries, its use as live food for larval culture of several aquatic species apparently began only in the 1930s, when it was found that it provide an excellent food for newly hatched fish larvae (Seale, 1933; Gross, 1937; Rollefson, 1939; Van Stappen, 1996). Moreover, recent developments in aquaculture production of fish and shrimp have resulted in increased demands for *Artemia* as a valuable source of live feed (Tackaert *et.al.*, 1993). *Artemia* cysts can also be stored for long periods in cans and used as food requiring less than 24 hours of incubation, and this process is not labour intensive, making them the most convenient live food in aquaculture industry.

In the 1950s, *Artemia* cyst harvesting for commercial purpose started in the United States from the Great Salt Lake and the saltpans in the Bay of San Francisco. Cysts were marketed from both sites at a very low price (less than 10$/ kg). As aquaculture developed in 1960's and 70s, the use of *Artemia* also became widespread due to its nutritional value for larval organisms, as well as its low price (Bengtson, 1991). The increased interest in aquaculture research and development around the globe as well as a decrease in the cyst harvest from the Great Salt Lake resulted in a severe rise in the *Artemia* cyst price, which ranged from 50 to 100 $ per kilogram.

Since developing countries could not afford to import the expensive cysts from the USA, commercial cyst production began from new sources, including a number of developing countries. In the 1980s, new commercial products were available from Argentina, Australia, Brazil, Colombia, France and Thailand. Prices dropped dramatically and competition was aggressive between suppliers. A market survey in the early eighties estimated that the annual cyst consumption by aquaculture hatcheries was about 60 metric tons (Sorgeloos, 1986). On the other hand, Tackaert *et. al.* (1993) reported that the world market for *Artemia* cysts for the use in aquaculture is over 700 metric tons per year.

Currently, cyst production, availability and price are relatively stable due to the efforts in *Artemia* research and developments made in early 1980s. The prices of cyst are now quality dependent, ranging from 25$ per kilogram for Great Salt Lake cysts to 80$ per kilogram for cyst characterized by high yield and small napulii, which are pollutants free. Annually, over 2000 metric tons of dry *Artemia* are marketed world wide for on-site hatching into 0.4 mm napulii (Van Stappen, 1996). However, only the Great Salt Lake, Utah, USA, until recently, has been the source of the large majority of raw cyst material in the world market (Lavens *et. al.*, 2000).

It is generally known that no artificial feed formulation is yet available to completely substitute *Artemia* as a feed supply for marine fish and crustacean larvae. Therefore, marine larval culture still largly depends on *Artemia* as a major food source in commercial hatchery operations (Sorgeloos *at. el.*, 2001). The small size of *Artemia* and dormant eggs called cysts, may be the reason why they are a convenient,

suitable and excellent larval food source (Leger *et.al.*,1986). These cysts are available all- year round in large quantities in hypersaline lakes, shorelines, solar saltworks distributed worldwide (Persoone,1980; Vanhaecke, 1983; Tackaert, 1985).

Corbin *et. al.* (1983) reported that, in marine aquaculture production around the world, *Artemia* nauplii are the principal food during the first weeks of larval rearing. Nonetheless, the culture of the fresh water prawn is also dependent on *Artemia* nauplii as the most successful food during their larval stages (Leger *et. al.*, 1986). In addition, Leger *et.al* (1986) claimed that the nutritional value of on-grown *Artemia* is more superior compared to the freshly hatched nauplii, i.e. protein content (on dry weight basis) increases from an average of 47% in nauplii to 60% in adults. Moreover, protein quality improves as adults are rich in amino acids. They also reported that the exoskeleton of adult *Artemia* is extremely thin which inhances the digestion of the whole animal by the predator.

A study carried out by Kim *et.al* (1996) showed that Coho salmon fry fed adult *Artemia* grew significantly faster than fry fed on other tested diets, and that was due to the increase in food intake. However, juvenile *Artemia* are generally used more intensively than adult *Artemia* just before weaning (Olsen *et.al.* , 1999; Lee *et.al.* , 1996).

In 1969, Mead and Finamore had discovered the Ascorbic acid 2-sulphate (AAS) which is a stable derivative of Ascorbic acid in dormant cysts of *Artemia*. Ascorbic acid (Vitamin C), is considered to be an essential dietary component for the various stages of aquaculture organisms for several biological and physiological

functions (e.g. skeletal development, growth, survival, immunoactivity) (Merchie *et.al*, 1997). Differences among geographical populations and *Artemia* species and broods from different years may significantly affect the AAS content in the cyst material and therefore would influence the Ascorbic acid levels in the freshly hatched nauplii and consequently, their nutritional value for larval fish (Sorgeloos *et.al*, 2001).

The nutritional value of *Artemia* is not restricted to its value as a live food. Experiments on encapsulated cysts, which are also called de-shelled or free-shell cysts have demonstrated that they can be used in start feeding for some freshwater species (Dehert *et.al*., 1997). Two series of feeding experiments were conducted to study the feasibility of using encapsulated *Artemia* cysts for direct feeding to ornamental fish by Lim *et al*., (2002). Their findings indicated that encapsulated cysts could be used as a substitute of *Artemia* nauplii in fresh water ornamental fish culture. The study showed also that the performance in terms of growth, survival and stress resistance of guppy adults and fry fed encapsulated *Artemia* cysts was better than to those fed *Artemia* nauplii or *Monia*.

Although the fresh-live form of *Artemia* has the highest nutritional value, harvested *Artmia* can be frozen, freeze-dried or acid-preserved for later use, and also, can be made in form of flakes or other formulated feed (Abelin *et.al*, 1991; Naessens *et.a*l, 1995).

Artemia biotopes are known to be feeding grounds for many birds and especially flamingos (Rooth, 1976). In the Great Salt Lake of Utah, the brine shrimp *A. franciscana* Kellogg is an important food resource for birds (Wurtsbaugh *et. al*.,

2001). Nonetheless, they are critical food resource for many migratory birds (Cooper *et. al.*, 1984)

Artemia and Research

Artemia have been widely used as a model organism for biochemical, physiological, genetic and ecological studies with more than 500 published papers (McCourt & Lavens, 1985). Several studies have estimated the environmental and genetic components of differences for life span and reproductive traits of *Artemia* (Kinne, 1963; Browne, *et.al*, 1984; Wear *et.al*, 1986; Browne, 1988; Vanhaecke, 1989; Triantaphyllidis *et.al.*, 1995; Browne & Wanigasekera, 2000; Herbest, 2001; Camara, 2001; Van Stappen, 2001; Browne *et. al.*, 2002). Most of these studies have focused on temperature and salinity, which are the most important physical parameters affecting the life history of hyper-saline organisms.

The combined effects of temperature and salinity on tolerance, survival and reproduction of *Artemia* have been investigated by many researchers. Vanhaecke *et. al.* (1984) examined the combined effects of temperature and salinity on the survival of 13 geographical strains covering four species. They noted that salinity resistance was high, the tolerance ranged from 3 ppt to 300 ppt. The results of that study were restricted to sub-adult survival, because the experiment period was limited to nine days.

Wear & Haslett (1986) and Wear *et. al.* (1986) studied the effects of salinity and temperature on *A. franciscana* from Lake Grassmere in New Zealand. They reported that more than 90% of the nauplii survived to maturity within a temperature

range of 20-28°C and 100-170 ppt salinity. They also noticed that adult *Artemia* were more tolerant than juvenile *Artemia* and they can initiate rapid population increase in the field at 15°C. However, no direct intraspecific or interspecific comparison could be made in their study because *A. franciscana* was the only species tested from Grassmere Lake.

Furthermore, *Artemia* populations were studied to determine the effects of temperature and salinity on hatchability of cysts, resistance of larvae, and biomass production (Vanhaecke & Sorgeloos, 1989). The authors tested *Artemia* under two salinity levels (35 ppt and 120 ppt) at four different temperatures (25°C, 30°C, 34°C and 37°C). Their results indicated that temperature tolerance was clearly affected by salinity. *A. salina* and *A. persimilis* strains were the least tolerant to high temperatures, with *A. franciscana* having the highest temperature tolerance and *A. parthenogenetica* strains intermediate.

Another study by Vanhaecke (1989) on the effects of increasing temperature on cyst hatching, as well as the temperature resistance of the larvae indicated that *A. franciscana* strains are most resistant, whereas *A. tunisiana* and *A. persimilis* strains were very sensitive to high temperatures and cyst hatchability was significantly affected in all *Artemia* strains. The hatching percentage was always maximal at 25°C up to 30°C, however, cysts hatching perform better at 25° C than at 30° C and the hatchability dropped continually with temperatures up to 37° C.

Moreover, two *Artemia* populations (a bisexual from San Francisco Bay & a parthenogenetic form from the Tanggu area in China) were assayed under laboratory

conditions, for their tolerance and fitness at various salinity levels (35, 60, 100, 140 and 180 ppt) all at 25°C (Triantaphyllidis, 1995). Salinity effects on special characteristics of the two *Artemia* populations, such as survival, growth rate, maturation, morphology, fecundity and life duration were also investigated. The study showed that the optimum salinity for *A. parthenogenetica* population was between 60 and 100 ppt, while *A. franciscana* appears to be more euryhaline exhibiting high survival and better reproductive characteristics at a wider range of salinity. A gradual increase in salinity resulted in better survival of *A. franciscana* up to 180 ppt. The results of this study indicated that salinity has a marked effect on the life cycle characteristics of both examined species.

In addition, a study on the competition between sexual and parthenogenetica *Artemia* rose as a single populations and as competitive cultures at 15°, 24° and 30°C was carried by Brata *et. al.*,(1996). Their results indicated that there are significant differences in competitive abilities between sexual and parthenogenetica strains when cultured together at different temperatures. Nonetheless, it indicated that the outcome is temperature- and strain-dependent, with the sexual species out-competing the parthenogenesis population at 15°C. Although, the parthenogenetica strain was the poorest competitor at 15°C and 24°C, the sexual species was the poorest competitor at 30°C.

It was proved that at least 60% of the embryos of *Artemia franciscana* survived for 4 years of continuous anoxia at physiological temperatures (20°-23°C) when fully hydrated, as reported by Clegg (1997). He found that these embryos seem to carry on metabolism during the first day of anoxia, however, no evidence for a continuing metabolism throughout the 4 years was obtained.

The combined effects of salinity and temperature on the survival and reproduction of five species of *Artemia* have been investigated by Browne *et al.*, (1988, 2000). The authors found that 15°C is near the lower temperature limit for successful *Artemia* reproduction. Their results also indicated that at 30°C, *Artemia* approach their limit for successful reproduction. However, salinity tolerance for the genus is higher than the 180 ppt upper limit used in the study, because four of the five species studied produced relatively high numbers of offspring at the highest salinity tested. The results of the study also indicated that the species which has higher reproductive output compared to other *Artemia* species at one temperature-salinity combination does not necessarily have a higher reproductive output at different temperature-salinity combination. This concludes that comparative analysis of different species based on just one temperature-salinity combination may be misleading.

The brine shrimp *A. franciscana* Kellogg of the Great Salt Lake of Utah produces dormant cysts that are harvested and used extensively in the aquaculture industry (Wutsbaugh *et. al*, 2001). They analyzed the limnological factors controlling *Artemia* growth and cyst production over 12 months in 1994 and 1995. Laboratory experiment showed that inter-brood intervals were highly dependent on temperature and slightly on food level. Juveniles reached reproductive size within 7 days under optimal temperatures and nutrition food where they grew rapidly and reached length of 9 mm after 9 days. In winter, when the temperature was below 3°C, *Artemia* were absent from the lake and phytoplankton abundance was high. In spring, when the

temperature was above 20°C, cysts hatched and *Artemia* grew and produced large clutches of ovoviviparous eggs.

An *Artemia* clone was isolated from pathenogenetic population of M Embolon saltworks (Thessaloniki, Greece) and analyzed for 10 reproductive and life span characteristics under laboratory conditions (Abatzopoulos *et. al.*, 2003). The reproductive performance of this species was tested at three selected salinities (50, 80 and 120 ppt) at a constant temperature of 22°C, while another clone was tested for the same performance at three different temperatures (22, 26 and 30°C) at a constant salinity of 80 ppt. The interclonal comparison revealed that salinity had a major impact on five out of six reproductive traits studied. At salinity of 80 ppt, the clone had the highest reproductive output expressed as total off-spring per female. Abatzopoulos *et. al.* (2003) found also that the life span characteristics were affected by salinity. Higher salinities caused delay in growth development (e.g. at 120 ppt the first brood occurred after 41 days). On the other hand, their study also showed that the temperature had an influence on the reproductive traits that were studied. The results revealed that, at 22°C the clone had the highest reproductive output expressed as total number of off-spring per female. Their overall conclusion was that the clone performed best at 80 ppt and at temperature of 22°C.

The lunar cycles are known to influence the behaviour of aquatic organisms, although the magnitude of such influence is not well understood. A study was conducted in two different locations in Colombia to determine the effect of medium-term cycles (lunar cycles) on the presence of *A. franciscana* density (Camargo, 2002).

During the two year study, no significant difference was found between increasing and decreasing moon phase. Also, *Artemia* density was not significantly higher during the new moon than at full moon.

From the foregoing discussion, it is clear that, temperature tolerance of some populations was clearly affected by salinity. *A. salina* and *A. persimilis* strains were the least tolerant to high temperature, while *A. franciscana* have the highest temperature tolerance and *A. parthenogenetica* strains have intermediate tolerance.

Materials and Methods

Materials and Methods

This study was conducted in two stages. The first stage aimed at studying the distribution of *Artemia* sp. in natural environment of Al Wathba Lake, together with an assessment of various environmental parameters at the sampling sites. The second stage evaluated *Artemia* survival under a range of individually-manipulated environmental conditions.

A. Field Study and Analysis

Sampling design

1. Sampling sites for the survey were chosen based on a 100 m grid overlaid on a geo-corrected digital satellite image of the Al Wathba Lake managed area. 14 sampling locations were chosen at the intersection of horizontal and vertical gridlines.

2. All sites occurring over the water body were identified and the co-ordinates entered into hand-held geographic positioning system (GPS) units (Garmin 175) using map source software (Fig.3).

3. Samples collection was carried out monthly at day time for ten months (April 2002- January 2003).

4. Surface and near-bottom samples were collected from each station. In case of water depth is less than 50 cm, samples were only collected from surface water.

Figure 3 Map showing *Artemia* sampling points at Al Wathba lake

Sampling Materials and Equipment

The following equipments were used in the monthly sampling:

1. Small electric motor boat
2. GPS (Geographical positioning system unit "Garmin 175")
3. 23 sampling bottles (2.2 litre)
4. Multimeter sensor
5. Horizontal water sampling device (Van-dorn water sampler)

Sampling Procedures

1. During each sampling month, the boat was loaded every time with the main equipment (sampling bottles, horizontal water sampling device, multimeter and GPS unit).
2. Using the GPS receiver, the boat was navigated to the starting sampling point (W6644), and from there along a pre-designated route to sequential sampling points up to the final sampling point (W5851).
3. At each site, the horizontal sampling device was deployed for surface sample collection.
4. The sample was poured into an appropriately labelled sampling bottle. Temperature and pH were measured in *situ* using the multimeter.
5. If the site depth was more than 50 cm, another (deep) sample was collected from the near-bottom layer using the horizontal sampling device, and stored in a labelled sample bottle. Temperature and pH were measured *in situ* using the multimeter.
6. Time of collection for each sample was recorded in the survey sheet.
7. The collected water samples were used to measure the following parameters:

I. Physical and chemical parameters.

1. Salinity and Conductivity

Materials

1. Distilled water
2. Multimeter sensor
3. Graduated cylinder (50ml)

Method

1. 10 ml of the water samples was diluted up to 50 ml with distilled water.
2. Salinity and conductivity were measured using the multimeter.
3. The reading of the salinity and conductivity were multiplied by 5 for the final result.

Salinity = Dilution reading x 5 = sample salinity (ppt)

2. Chemical Analysis

Water samples were analyzed for the main nutrients as well as calcium and magnesium concentrations using the automated San ++ analyzer (Skalar). All chemical analyses were carried out at the laboratories of the Environmental Research and Wildlife Development Agency (ERWDA) in Abu Dhabi, according to EPA methods for chemical analysis of water and wastes (EPA, 1983).

2.1 Nitrite

Principle

The automated determination for the nitrite was based on the following reaction:

The diazonium compounds formed by diazotizing of sulfanilamide by nitrite in water under acid conditions are coupled with α-naphthylehylenediamine dihydrochloride to produce a reddish-purple colour which is measured at 540nm.

Reagents and Standards Preparation

A. Distilled water + Brij 35

Preparation

1. Brij 35 diluted in 1 litre distilled water and stored at 4°C. The solution is stable for one week only.

B. Colour Reagent

Preparation

1. O-phosphoric acid was diluted in ± 700ml of distilled water.
2. The sulfanilamide and the α-naphthylethylene were added and filled up to 1 litre with distilled water.
3. The solution was stored at 4°C in a dark bottle and was stable only for one week.

C. Stock solution 100ppm N

Preparation

1. The sodium nitrite was dissolved in ±800ml distilled water.
2. The solution mixture was filled up to 1 litre with distilled water.
3. The solution was stored at 4°C which was stable for one month.

D. Stock solution 10ppm N

1. 10ml of stock solution 100ppm N was diluted to 100 ml with distilled water.

2.2. Nitrite + Nitrate

Principle

The automated determination of nitrite and nitrate was based on the cadmium reduction method. The sample was passed through a column containing granulated copper-cadmium to reduce nitrate to nitrite. The nitrite (originally present plus reduced nitrate) was determined by diazotizing with sulfanilamide and coupling with α-naphthylenediamine dihydrochloride to form a highly coloured azo dye which is measured at 540 nm.

Reagents and Standards Preparation

A. Buffer solution

Preparation

1. Ammonium chloride was dissolved in ± 800 ml distilled water.
2. pH was adjusted to 8.2 using the ammonium hydroxide solution.
3. Birj 35 was added to the solution and then filled up to 1 litre with distilled water.
4. The solution was stored at 4°C which was stable for one week.

B. Colour reagent

See page 35

C. Stock solution (100ppm N)

Preparation

1. The sodium nitrate was dissolved in ± 800 ml and filled up to 1 litre.
2. The solution was stored at 4°C which was stable for one month.

D. Stock solution (10 ppm N)

1. 10 ml of stock solution 100ppm N was diluted in 100 ml of distilled water.

2.3. Phosphate

Principle

The automated procedure for the determination of phosphate was based on thefollowing reaction:

Ammonium molybdate and potassium antimony tartrate react in an acidic medium with diluted solutions of phosphate to form an antimony-phospho-molybdate complex. This complex was reduced to an intensely blue-coloured complex by ascorbic acid. The complex is measured at 880 nm.

Reagents and Standards Preparation

A. Water digest

The water sample was digested with sulphuric acid, potassium sulfate and mercuric sulfate as catalyst. Amino nitrogen of many organic materials was converted into ammonium sulfate. Free ammonia and ammonium nitrogen were also converted into ammonium sulfate. Phosphorus was transferred into ortho-phosphate.

Mercuric sulfate solution

1. 8 g of red mercuric oxide (HgO) was dissolved in 100 ml sulphuric acid (H_2SO_4 1.8M).

Digestion solution

1. 134 g of potassium sulfate were added in 1 litre beaker.
2. 650 ml of distilled water and 200 ml of concentrated sulphuric acid were added.
3. 25 ml of mercuric sulfate solution were added while stirring.
4. Distilled water was added up to 1 litre.

Water digestion preparation

1. 25 ml of the water sample were added into digestion tube. Blank sample was also prepared consisting of 20 ml distilled water.
2. Few TFE fluorocarbon boiling stones were added.
3. While mixing, 5 ml of the digestion solution was added.
4. The digestion block was pre-heated to 160°C.
5. The digestion tube was inserted into the digestion block and heated for 1 hour at 160°C.
6. Later, the digestion block was heated to 380°C for 2-2 ½ hour.
7. The digestion tube was removed from the digestion block and left to cool down.
8. Carefully, 20 ml of distilled water were added and mixed.
9. Distilled water was added up to 75ml.

B. Ammonium molybdate solution

Preparation

1. Potassium antinmony tartrate was dissolved in ± 800 ml of distilled water.
2. While swirling and cooling, sulphuric acid was added.
3. Ammonium molybidate was added and filled up to 1 litre with distilled water.
4. Finally, FFD6 was added to the solution.

C. Preparation of ascorbic acid solution

1. Ascorbic acid was dissolved in ± 800 ml of distilled water.
2. Then, the Aceton was added and filled up to 1 litre with distilled water.
3. Finally, FFD6 was added to the solution.

D. Preparation of stock solution (100ppm P)

1. Potassium dihydrogen phosphate was dissolved in ± 800ml distilled water.

2. The solution was filled up to 1 litre with distilled water.

E. Stock solution (10ppm P)

10 ml of stock solution 100ppm P was diluted to 100 ml with distilled water.

2.4. Ammonia

Principle

The automated procedure for the determination of ammonia is based on the modified Berthelot reaction. Ammonia is chlorinated to monochloramine which reacts with phenol. After oxidation and oxidative coupling a green coloured complex is formed. The reaction is catalysed by nitroprusside, sodium hypochlorite is used for chlorine donation. The absorption of the formed complex is measured at 630 nm.

Reagents and Standards Preparation

A. Water digest

See page 38

B. Preparation of buffer solution

1. Potassium sodium tartrate was dissolved in ± 800ml of distilled water.

2. Then sodium citrate was added and the pH adjusted to 5.0 using sulphuric acid solution.

3. The mixture was filled up to 1 litre with distilled water and Birj 35.

4. The solution was stored at 4°C and was stable for one week.

C. Preparation of Phenol solution

1. Phenol was dissolved in ± 50 ml of distilled water.

2. Then sodium hydroxide was added and filled up to 1 litre with distilled water.

D. Sodium hypochlorite solution

Preparation

1. Sodium hypochlorite was diluted in ± 700ml distilled water.
2. Then the solution was filled up to 1 litre with distilled water.
3. The solution was stored at 4°C and was stable for one week.

F. Sodium nitroprusside solution

Preparation

1. Sodium nitroprusside was dissolved in ± 800ml.
2. The solution was filled up to 1 litre with distilled water.
3. The solution was stored in dark coloured bottle.

G. Air scrubber solution (2.5M sulphuric acid solution)

Preparation

1. Carefully, the sulphuric acid was diluted in ± 800ml of distilled water
2. The solution was filled up to 1 litre with distilled water.

II. Biological parameters

Sampling of *Artemia* and cysts

At each station, *Artemia* and cysts samples were also collected both at surface and near-bottom levels using the Van-Dorn water sampler. The collected samples were kept in big plastic containers and the following processes were undertaken in the laboratory.

1. Evaluation of *Artemia* and cyst densities

Method

1. The sample volume was measured using graduated cylinder.

2. Each sample was filtered separately using the filtration device plankton net mesh size 20 μm.

3. The collected organisms and cysts from the filtration process were washed with distilled water.

4. *Artemia organisms* (adults and nauplii) were counted in the whole sample using the stereomicroscope.

5. 2ml of the concentrated sample was taken for cyst counting under stereomicroscope.

6. The above step (# 4) was repeated 3 times.

7. For the calculation for cyst density in 1000 ml of the sample the

Following equation was applied:

Total cyst/1000 ml = ((total cyst/6ml) x 1000)

B. Laboratory Experiments

***Artemia* optimal living conditions experiments**

The *Artemia*, cyst and water used in these experiments were obtained from the same study site (Al Wathba Lake). Salinity, temperature, pH and food type preference were the main four parameters that have been tested in these experiments. These experiments were carried out under light (12:12L:D) and temperature controlled incubators at the Biology Department, Faculty of Science,UAE University.

The conditions and the parameters of theses experiments are described in details here below:

1. Water sample filtration

Method

1. 20 litres of water sample were filtered through GFC 47 mm filter paper.

2. All the filter papers were dried in an oven at 30°C for cyst collection.

3. Filtered water was sterilized in an autoclave for 15 minutes at 110°C and cooled down for 1½ hour. Sterilization process was carried out in autoclave to kill any living organism in the water.

2. Salinity adjustment and salinity tolerance experiemnt

Method

1. 1000 ml of brine water was prepared using NaCl added to the water sample from the lake.

2. The salinity of the brine solution prepared was adjusted to 200 ppt and measured using the multimeter.

3. Three replicates of 100 ml of the solution (200 ppt) were added in 250 ml conical flask.

4. Another solution with salinity of 150 ppt was prepared from diluting the previous prepared brine sample (200 ppt) with distilled water. Salinity of the sample was measured using the multimeter.

5. Three replicates of 100 ml of the solution (150 ppt) were added in 250 ml conical flasks.

6. A solution with salinity of 125 ppt was prepared from diluting the previous prepared brine sample (200 ppt) with distilled water. Salinity of the sample was measured using the multimeter.

7. Three replicates of 100 ml of the solution (125 ppt) were added in 250 ml conical flasks.

8. A solution with salinity of 100 ppt was prepared from diluting the previous prepared brine sample (200 ppt) with distilled water. Salinity of the sample was measured using the multimeter.

9. Three replicates of 100 ml of the solution (100 ppt) were added in 250 ml conical flasks.

10. A solution with salinity of 75 ppt was prepared from diluting the previous prepared brine sample (200 ppt) with distilled water. Salinity of the sample was measured using the multimeter.

11. Three replicates of 100 ml of the solution (75 ppt) were added in 250 ml conical flasks.

12. Three individuals of *Artemia* were added in each conical flask with 1ml of *Dunaliella* added in each flask.

13. A total of 15 solutions were prepared with different salinities (200 ppt, 150 ppt, 100 ppt, 125 ppt, 75 ppt) and with three *Artemia* individual in each with total of 45 individuals.

14. All flasks were incubated at 25°C. (Diagram. 1)

3. pH

Method

1. The pH for the water sample from the study site was measured using the multimeter device. pH measured was 8.4.

2. Solutions with pH 8 and 7 were prepared. The pH of the water was adjusted by adding drops of (0.01 M) HCl and measuring it with the multimeter.

3. Three replicates of 100 ml water sample (salinity =75 ppt) of each pH (7 and 8) were added in 250ml conical flasks.

4. Solutions with pH 9, 9.5 and 10 were also prepared. The pH of the water was adjusted by adding drops of NaOH and measuring it with the multimeter.

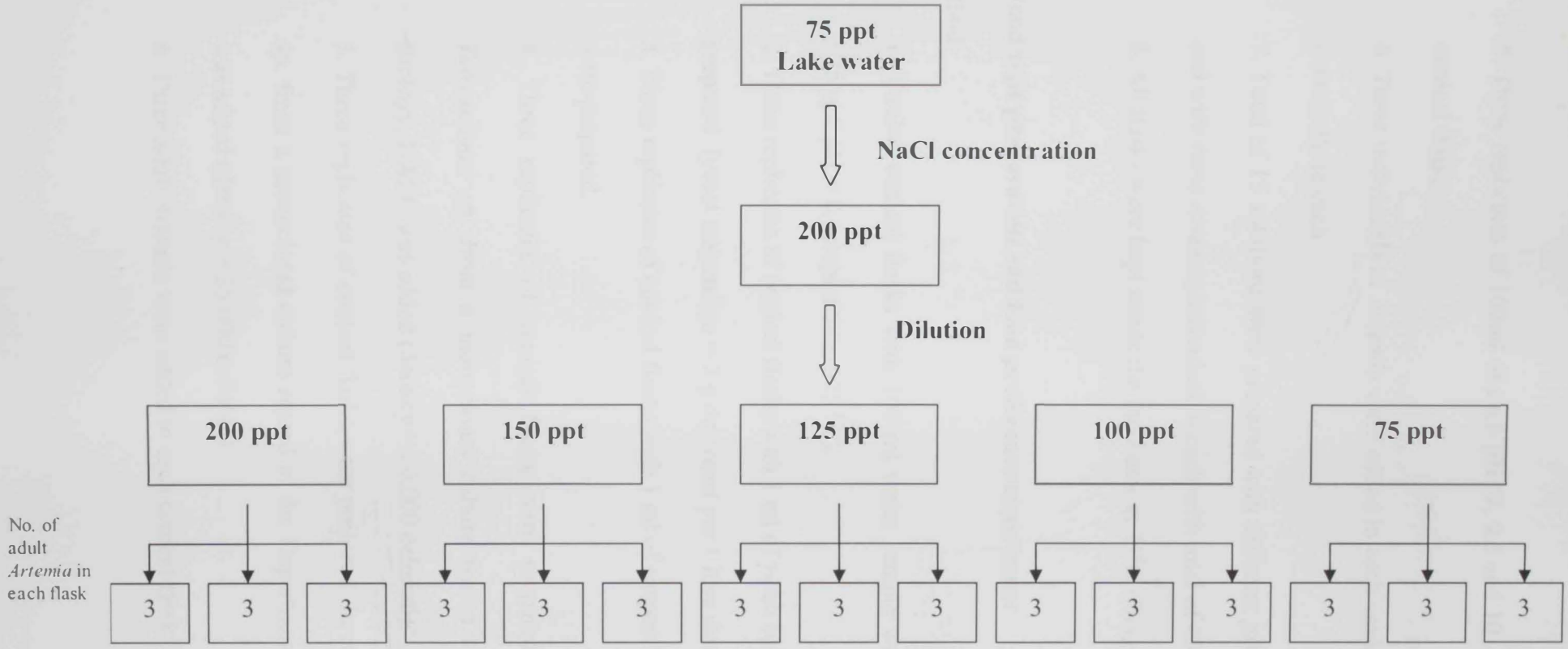

Diagram 1. Experimental design for studying *Artemia* tolerance under different salinity range.

5. Three replicates of 100ml of each pH (9, 9.5 and 10) were added in 250ml conical flasks.

6. Three individuals of *Artemia* were added in each conical flask with 1 ml of *Dunaliella* in each.

7. Total of 15 solutions were prepared with different pH (7, 8, 9, 9.5 and 10) and with three *Artemia* individual in each with total of 45 individuals.

8. All flasks were kept inside the incubator at 25°C (Diagram.2).

4. Food type preparation and food preference experiment

Method

1. Twelve conical flasks with 100 ml water sample were prepared (salinity =75 ppt, pH = 8, temperature = 25 °C).

2. Three replicates of conical flasks with 1 ml of yeast suspension in each were prepared. (yeast suspension = 3 g dry yeast per 1 litre distilled water)

3. Three replicates of conical flasks with 1 ml of suspended *Dunaliella* in each were prepared.

4. Three replicates of conical flasks were prepared. In each 1 ml of *Tetraselimus sp.* from a monoclonal culture reared at the Department of Biology, UAEU was added (density = 20,000 cells/ml).

5. Three replicates of conical flasks were prepared. In each 1 ml of *Chlorella* sp. from a monoclonal culture reared at the Department of Biology, UAEU was added (density = 35,000 cells/ml).

6. Three adult *Artemia* were added to each conical flask.

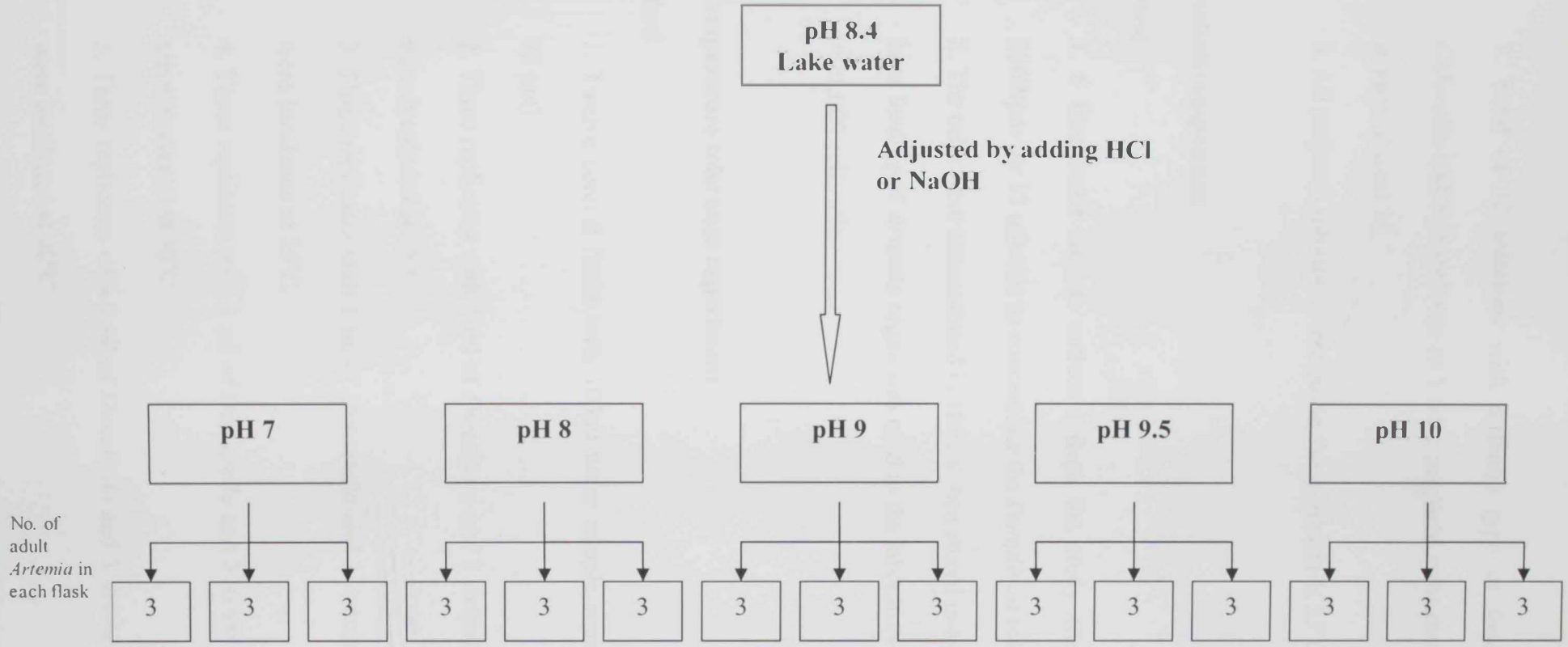

Diagram 2. Experimental design for studying Artemia tolerance under different pH range.

7. Total of 12 solutions with different type of food (yeast, *Dunaliella*, *Chlorella* and *Tetraselimus sp.*) were prepared with three *Artemia* individual in each of total 36.

8. All prepared solutions were put in the incubator at 25°C. (Diagram.3)

***Dunaliella* suspension**

Method

1. 5 litre water sample collected from the study site was centrifuged at 3500rpm for 12 minutes to concentrate the *Dunaliella* cells.

2. The cells were concentrated in 100 ml then stored in a glass bottle at 4°C for later feeding of *Artemia* organisms used in the laboratory experiments (density = 21,000 cells/ml).

5. Temperature tolerance experiment

Method

1. Twelve conical flasks with 100ml water sample were prepared (salinity = 75 ppt).

2. Three replicates with 1 ml of *Dunaliella* and 3 *Artemia* individuals in each were incubated at 15°C.

3. Three replicates with 1 ml of *Dunaliella* and 3 *Artemia* individuals in each were incubated at 25°C.

4. Three replicates with 1 ml of *Dunaliella* and 3 *Artemia* individuals in each were incubated at 30°C.

5. Three replicates with 1 ml of *Dunaliella* and 3 *Artemia* individualsnin each were incubated at 40°C.

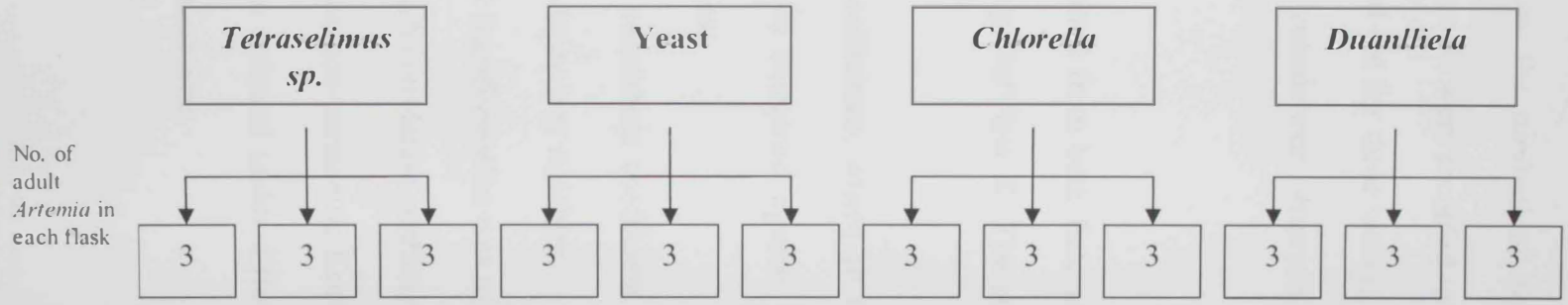

Diagram 3. Experimental design for studying *Artemia* tolerance in different types of food.

6. Total of 12 solutions were incubated at different temperatures (15°C, 25°C, 30°C and 40°C) and with 3 three *Artemia* individual in each with total of 36. (Diagram.4)

In all experiments, the survival of *Artemia* organisms was observed twice daily and the obtained results were recorded until the death of the last organism. The experiments were carried out for three weeks. In certain experiments with favouring conditions new born individuals were observed.

C. Statistical Analysis

The results obtained from both field and laboratory experiments have been treated statistically, using StatView ®. The statistical methods used in the present study were:

1- Correlation coefficients: where all field parameters measured during the study period were examined against themselves and against the *Artemia* organisms and cysts.

2- The Pearson correlation coefficient was calculated between each of the independent and dependent variables.

3- Fisher's r to z transformation was used to calculate a probability (p value) to determine if each correlation coefficient is significantly different from zero.

4- Fisher's and the non-parametric Kruskal-Wallis test were used to compare *Artemia* tolerance cultured under different treatments range of temperature, salinity, pH and food type.

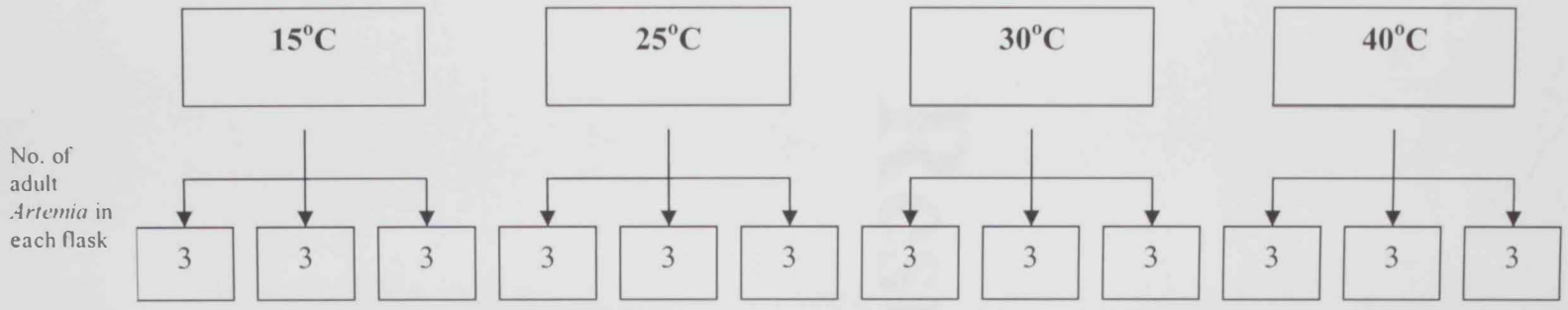

Diagram 4. Experimental design for studying *Artemia* tolerance incubated at different temperatures.

Results

1. Physical and Chemical Parameters of Al Wathba Lake

1.1. Air temperature

Air temperature at Al Wathba Wetland Reserve varied diurnally as shown by daily minimum and maximum temperatures (Table1). The highest temperatures were recorded during July (48.05°C) and the lowest were recorded during January (8.03°C) (Fig. 4).

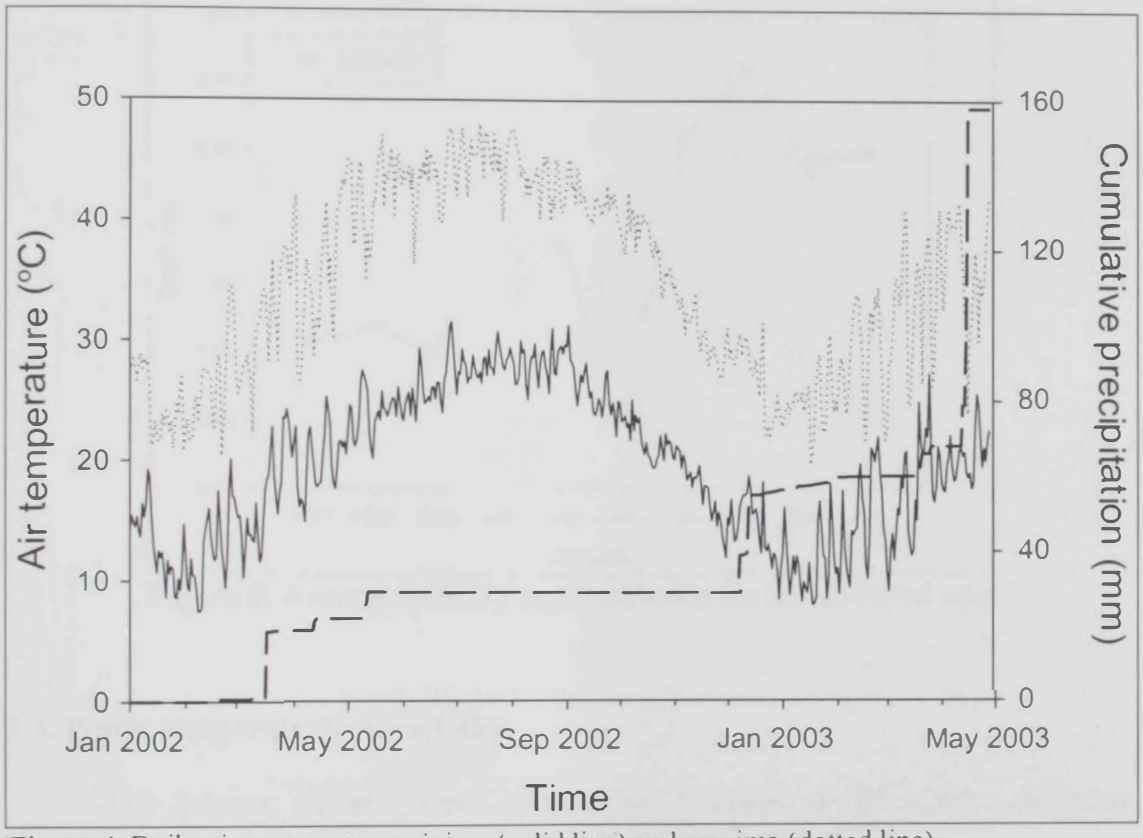

Figure 4. Daily air temperature minima (solid line) and maxima (dotted line) and cumulative precipitation measured daily (long dashed line) for the Al Wathba area during the study period from April 2002 to January 2003.
(Data from Water Resource Studies Department)

P.s. All tables are listed at the appendix caption.

1.2. Lake depth

Lake depth was very variable spatially, by sampling location, and seasonally (Table 2). On average, location W6047 was the deepest (1.5 – 2m) while location Hyper1 was the shallowest (0.4 – 1m). The lowest depth recorded during the whole period of the survey was in September, while the highest record was in November (Fig.5).

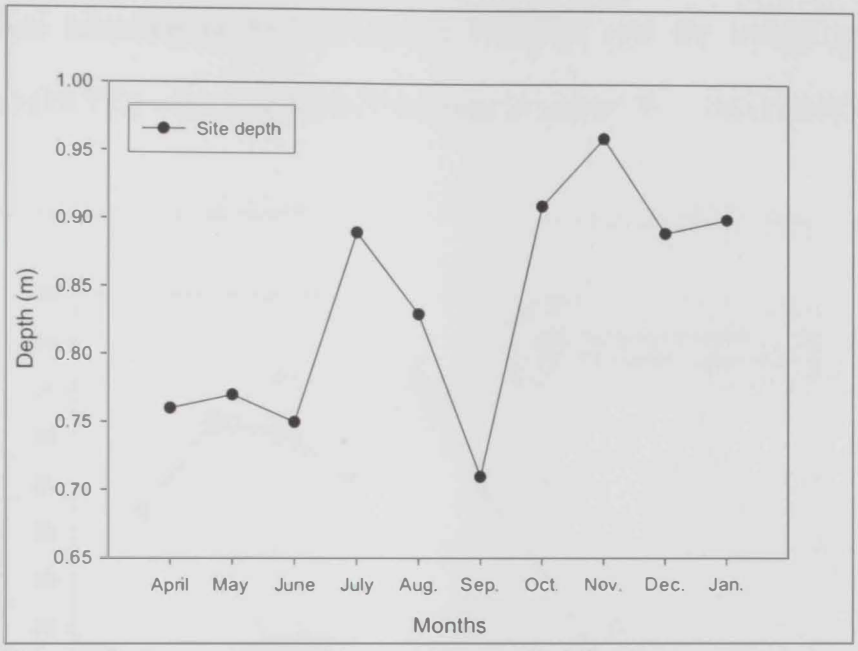

Figure 5. Average monthly depth recorded for the surveyed sites

1.3. Water temperature of the Lake

The average surface water temperature recorded at the various sampling locations on the lake during the survey in 2002 ranged from 34.5°C in August to 18.6°C in December. The average near-bottom temperature recorded for the lake ranged from 35.2°C in August to 20.3°C in December. The annual pattern of mean water temperatures for surface waters and near-bottom is shown in figure 6. The surface and near-bottom temperatures follow a similar pattern with highest

temperatures occurring around August, decreasing through December followed by a gradual increase.

Based on the monthly surface water temperatures recorded for each station, the highest temperature was recorded in August-September (38.1°C) at station W6050 and the lowest surface water temperature was (18.2°C) recorded in December at the same station (Table 3). On the other hand, the highest near-bottom temperature (41.5°C) was recorded in July at station W5950D and the lowest near-bottom temperature (18.7°C) was recorded in December at station W5749D (Table 4).

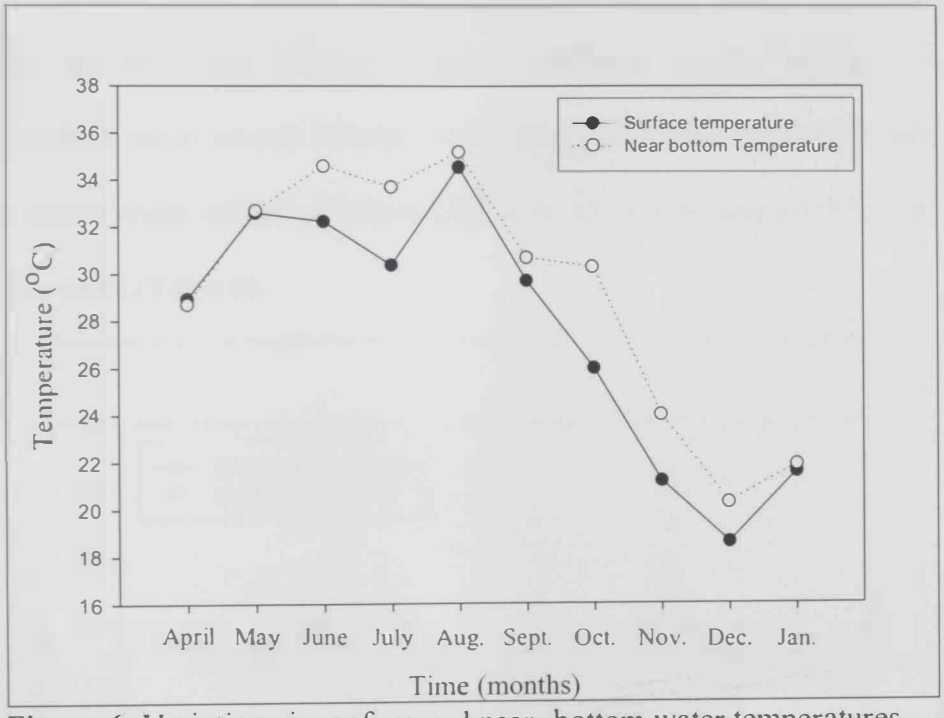

Figure 6. Variations in surface and near- bottom water temperatures during the sampling period, from April 2002 to January 2003.

1.4. Salinity

The mean surface salinity of the lake varied from a high of 177.2 ppt in November to a low of 70.4 ppt recorded in December. However, the mean near-

bottom salinity of the lake ranged from a high of 202.4 ppt in November to a low of 81.2 ppt in October (Fig.7).

At the water surface, the highest salinity was recorded at station Hyper1 in June (237.5 ppt). This station also had the highest mean salinity during the study period (Table 5). The lowest salinity was recorded at station W5851 in July (11.5 ppt), and this station also had the lowest mean salinity (95.9 ppt) during the study period.

The highest near-bottom salinity recorded was 236.5 ppt at station Hyper1 in September, and the lowest 55.2 ppt at station W5950 in October. Station Hyper1 also had the highest mean annual salinity (160.4 ppt) while stations W5950 and W6047 had the lowest mean annual salinities (127.6 & 127.4 ppt, respectively) of all near bottom locations (Table 6).

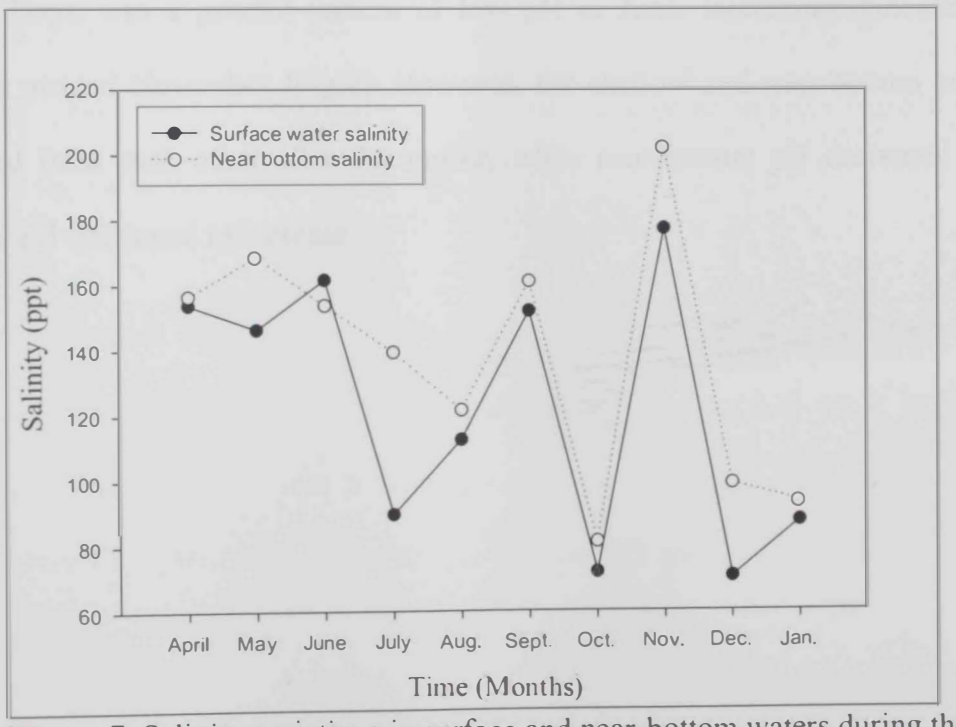

Figure 7. Salinity variations in surface and near-bottom waters during the study period. (April 2002 to January 2003).

1.5. pH

The pH data for surface and near-bottom waters collected from the lake are shown in Tables 7 and 8. Monthly samples showed that, for surface waters the highest pH value was 10.07 and has been recorded in November at station W5950, while the lowest surface pH of 7.6 was recorded at station W6050 in June. For near-bottom, the most alkaline pH of 10.1 was recorded at station Hyper1 in November, while the lowest pH of 7.6 was recorded at station W6246D in December.

The overall, mean surface water pH ranged from 7.8 in June to 9.95 in November, while at near-bottom the pH ranged from 7.8 also in June to 9.4 in September. For surface waters, station W5950 had the highest mean pH (9.0) and station W6644 the lowest, while for near-bottoms station, Hyper1 had the highest mean pH (9.13) and station W6246 (pH 8.49) the lowest.

There was a general pattern of low pH in June, increasing thereafter and peaking around November (Fig.8). However, the shallow and near-bottom patterns diverged from each other after September, when near-bottom pH decreased while shallow pH continued to increase.

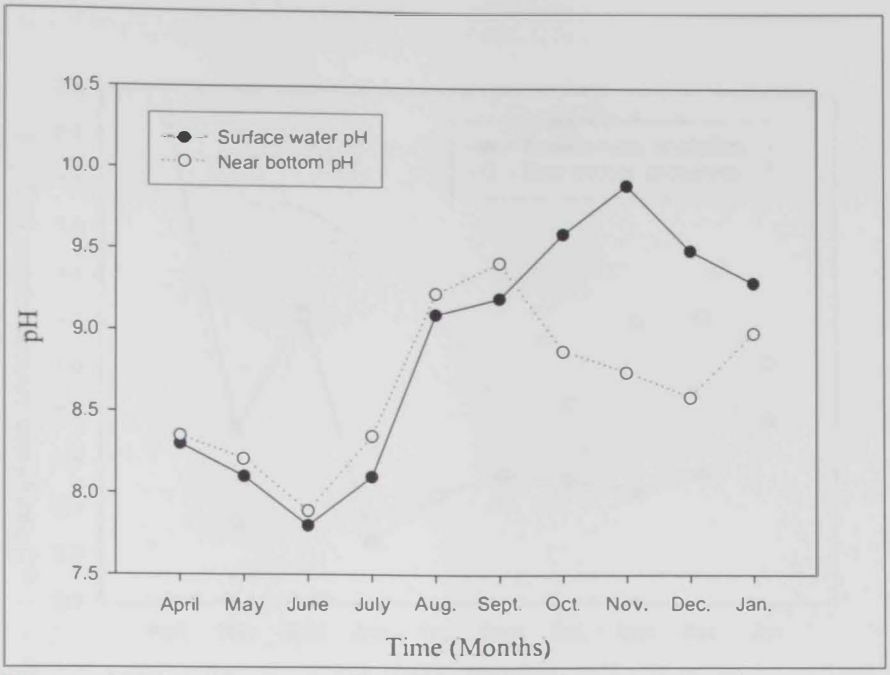

Figure 8. Monthly mean pH values of surface and near-bottom waters during the study period, from April 2002 to January 2003.

1.6. Phosphate (PO_4)

At the lake surface waters, the highest concentration of phosphate (4.27 mg l^{-1}) occurred at W6074 in May and the lowest concentration (0.1 mg l^{-1}) occurred at site W5749 in July (Table 9). For near-bottom waters, the highest phosphate concentration (2.58 mg l^{-1}) occurred at site W6246 in December, and the lowest concentration (0.11 mg l^{-1}) at the same site in July (Table 10).

The overall monthly mean phosphate values for surface water ranged from 2.09 mg l^{-1} in April to 0.46 mg l^{-1} in July, while it ranged from 2.07 mg l^{-1} in April to 0.34 mg l^{-1} in May for near-bottom waters. The general pattern was for high concentrations of phosphate during the cooler months and lower values during the summer months (Fig.9).

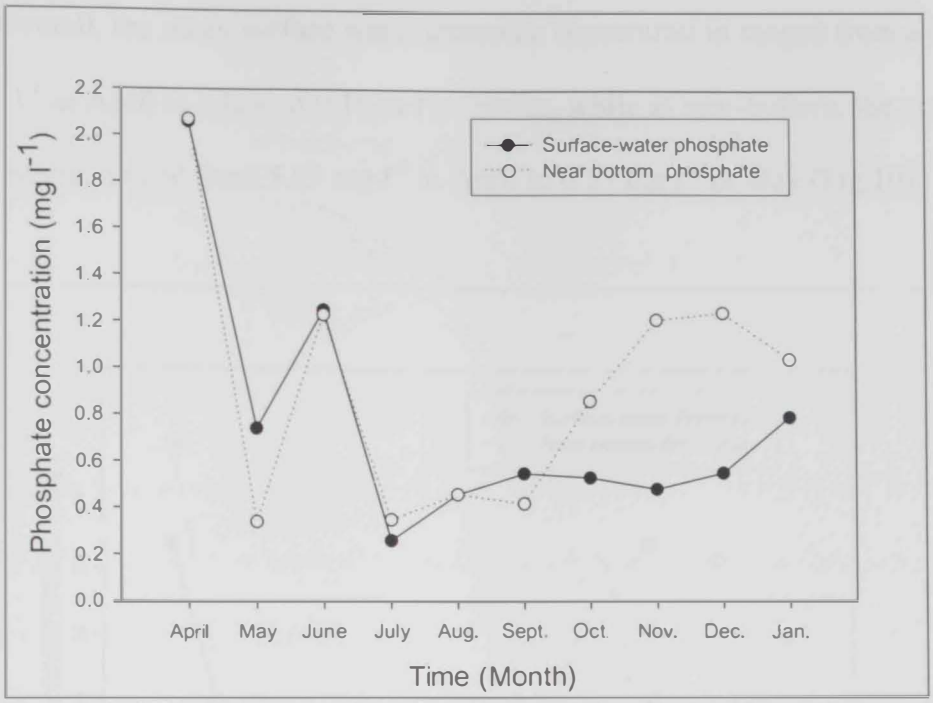

Figure 9. Monthly mean phosphate values of surface and near-bottom locations during the study period from April 2002 to January 2003.

1.7. Ammonia

The ammonia concentrations data for surface and near-bottom waters are shown in Tables 11 and 12. For surface waters, the highest ammonia concentration (5.64 mg l^{-1}) was recorded in April at station W6246, while the lowest concentration (0.1 mg l^{-1}) was recorded at stations Hyper2 and W5749 in December. For near-bottom water, the highest ammonia concentration (9.78 mg l^{-1}) was recorded at station W6047 in January, while the lowest concentration (0.1 mg l^{-1}) was measured at Hyper1 and Hyper2 in December.

For surface waters, station Hyper2 had the highest mean annual ammonia concentration (2.09 mg l^{-1}) and station W6644 the lowest (0.65 mg l^{-1}) (Table 11), while for near-bottom waters, station W6047 had the highest mean ammonia concentration (4.11 mg l^{-1}) and station Hyper1 (0.79 mg l^{-1}) the lowest (Table 12).

Overall, the mean surface water ammonia concentration ranged from a high of 4.37 mg l^{-1} in April to a low of 0.16 in November, while at near-bottom, the ammonia concentrations ranged from 5.89 mg l^{-1} in April to 0.57 mg l^{-1} in May (Fig.10).

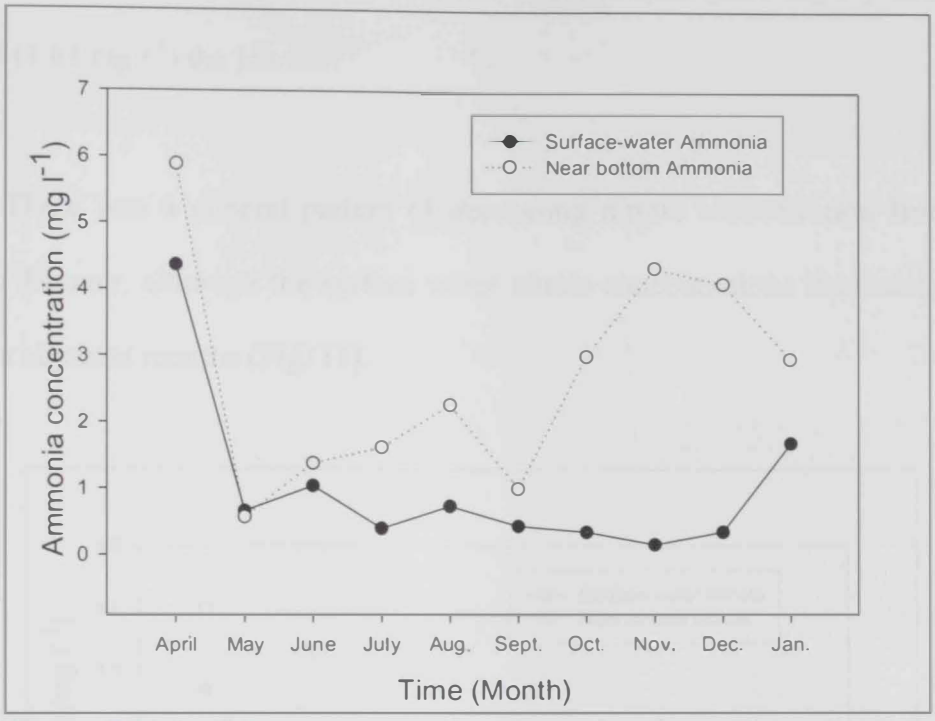

Figure 10. Monthly mean ammonia values of surface and near-bottom waters during the study period from April 2002 to January 2003.

1.8. Nitrate

Monthly samples showed that for surface waters, the highest concentration of nitrates (5.8 mg l^{-1}) was recorded in April at station W6146, while the lowest surface nitrate concentration (0.28 mg l^{-1}) was recorded at station W6047 (Table 13). For near-bottom waters, the highest nitrate concentration (7.9 mg l^{-1}) was recorded at station Hyper1 in April, while the lowest concentration (0.1 mg l^{-1}) was measured at W6246 in December (Table 14).

The overall, mean surface water nitrate concentration ranged from a high of 3.35 mg l^{-1} in April to a low of 1.02 mg l^{-1} in January, while at near-bottom, the

nitrate concentrations ranged from 4.0 mg l^{-1} in April to 0.75 mg l^{-1} in January. For surface waters, station W6049 had the highest mean annual nitrate concentration (2.51 mg l^{-1}) and station W6644 the lowest (0.65 mg l^{-1}), while for near-bottom waters, station W6047 had the highest mean nitrate concentration (2.51 mg l^{-1}) and station Hyper2 (1.62 mg l^{-1}) the lowest.

There was a general pattern of decreasing nitrate concentration from April through January, although the surface water nitrate concentrations fluctuated greatly between adjacent months (Fig. 11).

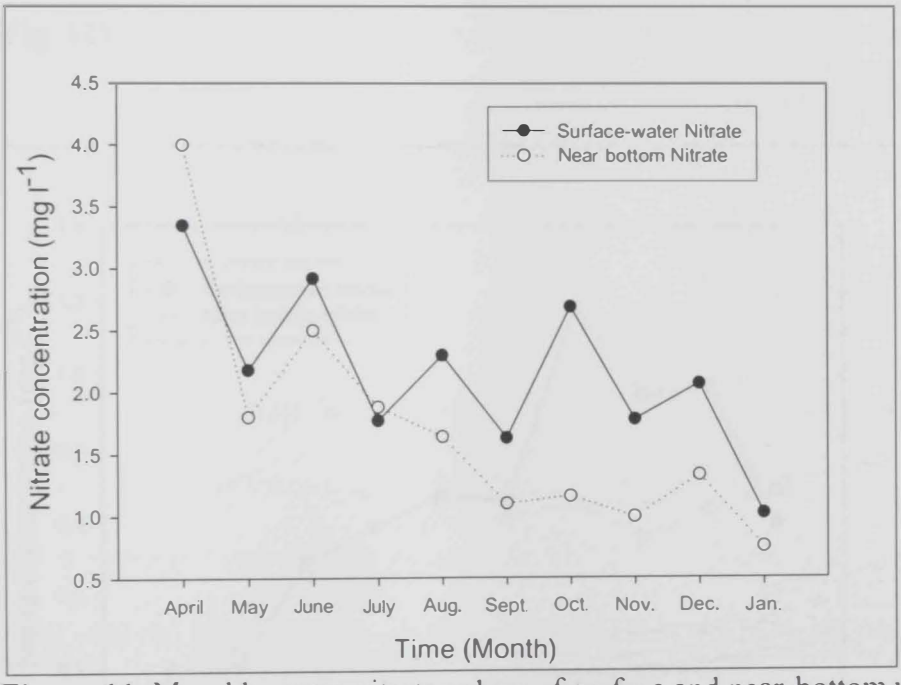

Figure 11. Monthly mean nitrate values of surface and near-bottom waters during the study period from April 2002 to January 2003.

1.9. Nitrite

For surface waters, the highest concentration of nitrites (1.52 mg l^{-1}) was recorded in July at station W6075, while the lowest surface nitrite concentration (0.07 mg l^{-1}) was recorded at station W5950 in April (Table 15). For near-bottom water, the

highest nitrite concentration (1.08 mg l^{-1}) was recorded at station Hyper1 in October, while the lowest concentration (0.08 mg l^{-1}) was measured at W5950 in April (Table 16).

The average surface nitrite concentration of the lake ranged from a high of 1.18 mg l^{-1} recorded in October to a low of 0.2 mg l^{-1} recorded in April and May, while it ranged from high values (0.68 mg l^{-1}) recorded in January and low values (0.1616 mg l^{-1}) recorded in April for the near-bottom nitrite concentration. There was a general pattern of gradual increase in nitrate concentration from April to September, followed by a sharp increase in October, and a gradual decrease thereafter until January (Fig. 12).

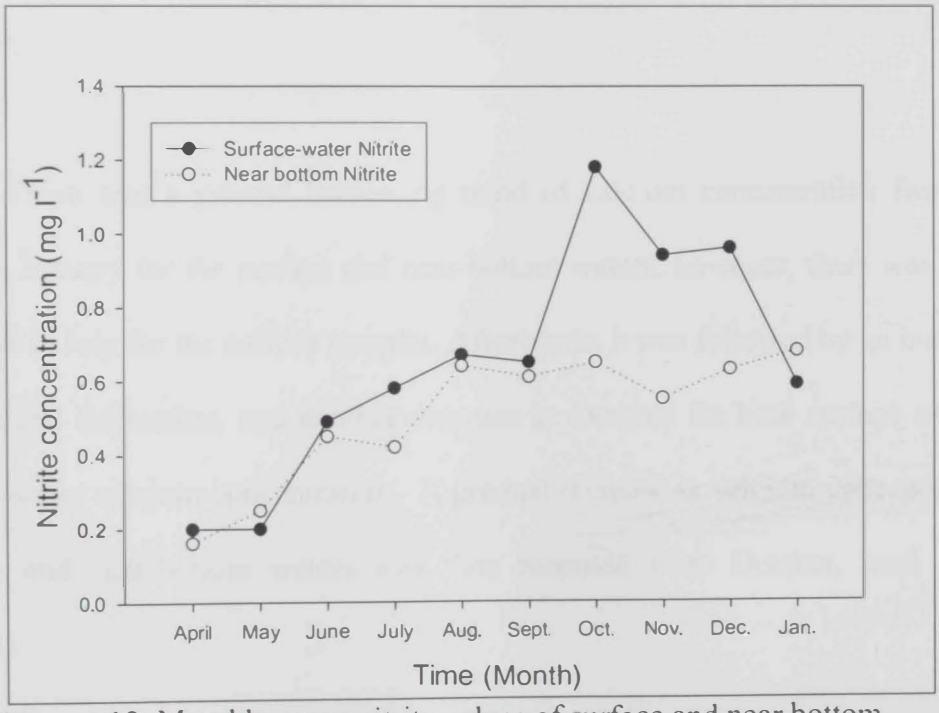

Figure 12. Monthly mean nitrite values of surface and near bottom waters during the study period from April 2002 to January 2003.

1.10. Calcium

The calcium concentration data for surface and near-bottom waters are shown in tables 17 and 18. Monthly samples showed that for surface waters, the highest calcium concentration (3563 mg l^{-1}) was recorded in April at station Hyper1, while the lowest calcium concentration (101 mg l^{-1}) was recorded at stations W5851 in July. For near-bottom waters, the highest calcium concentration (3574 mg l^{-1}) was recorded at station Hyper1 in April, and the lowest concentration (1463 mg l^{-1}) was also measured at Hyper1, in October.

The overall, mean surface water calcium concentration ranged from a high of 3229 mg l^{-1} in April to a low of 1261 mg l^{-1} in July, while at deep locations the calcium concentration ranged from a high of 3192 mg l^{-1} in April to 1978 mg l^{-1} in October.

There was a general decreasing trend of calcium concentration from April through January for the surface and near-bottom waters, however, there was a sharp decrease in July for the surface samples. Afterwards, it was followed by an increase in August and September, and another decrease in October for both surface and near-bottom water calcium concentration. A gradual increase in calcium concentration of surface and near-bottom waters was then recorded from October, until January (Fig.13).

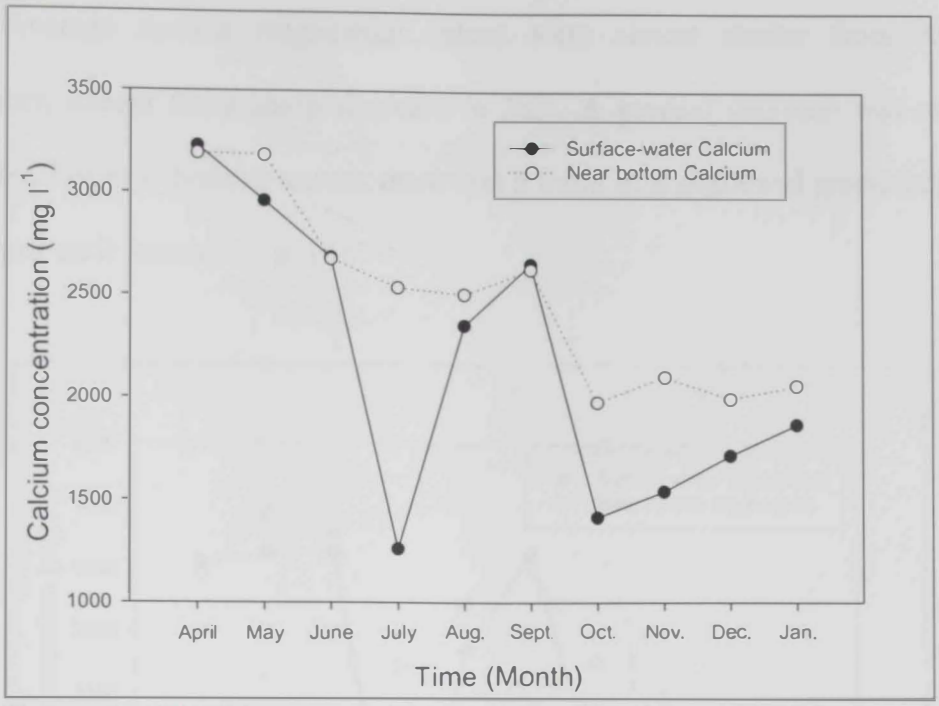

Figure 13. Monthly mean calcium values of surface and near bottom waters during the study period from April 2002 to January 2003.

1.11. Magnesium

The highest concentration of magnesium (6040 mg l^{-1}) in surface waters at Al Wathba Lake was found in June at the Hyper1 site, and the lowest concentration (123 mg l^{-1}) was found at the W5851 site in July (Table 19). Near the lake bed, the highest magnesium concentration (6325 mg l^{-1}) was again found at the Hyper1 location in June, but the lowest concentration (2012 mg l^{-1}) was recorded at site W5749 in December (Table 20).

The overall, mean surface water magnesium concentration ranged from a high of 4142 mg l^{-1} in June to a low of 1261 mg l^{-1} in July, while at near-bottom locations the magnesium concentration ranged from a high of 4427 mg l^{-1} in May to 2549 mg l^{-1} in December.

Average surface magnesium values were almost similar from April to September, except for a sharp decrease in July. A gradual decrease was recorded thereafter. For near-bottom waters, there was a trend of a slight and gradual decrease from April until January (Fig. 14).

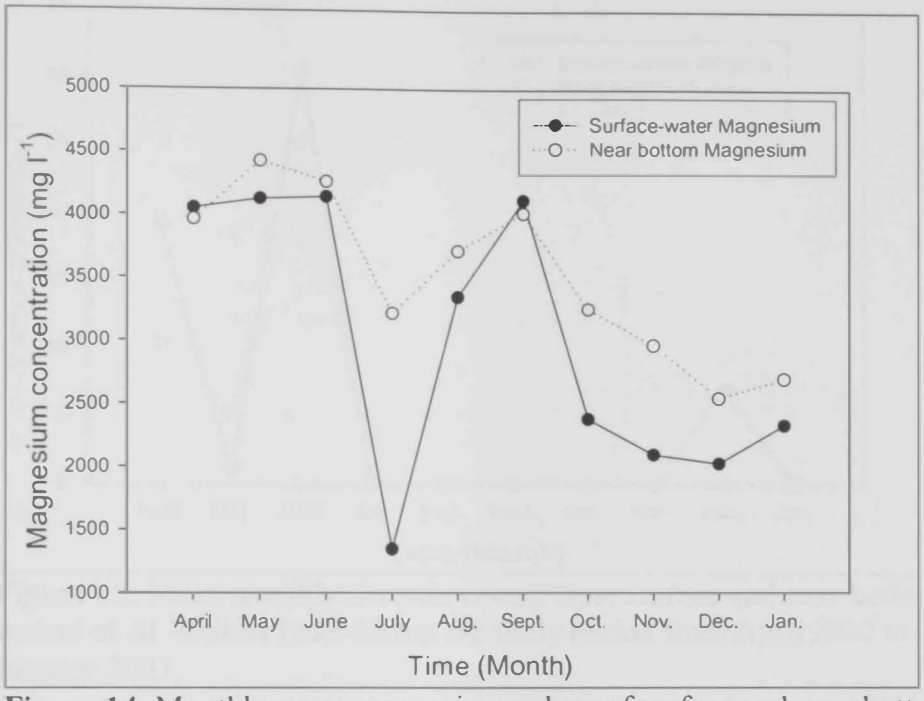

Figure 14. Monthly mean magnesium values of surface and near-bottom waters during the study period from April 2002 to January 2003.

2. Abundance of *Artemia* and *Artemia* Cysts in Al Wathba Lake

2.1. *Artemia*

Counts of *Artemia* present in the surface and near-bottom water samples from Al-Wathba Lake are given in Tables 21 and 22. In both cases, *Artemia* were present only during April, May and June (and in one surface sample in December). The greatest numbers were found at W6050 in April and again at W5950 in June, while throughout this period there were some locations with no *Artemia* detected in the water samples. Near-bottom samples tended to have fewer *Artemia,* with the highest numbers being recorded at location W6545 in June. Meanwhile, no *Artemia* were

detected in samples from many locations. The highest mean monthly counts were found in June for both surface and near-bottom locations (30.4 ind.l^{-1} and 25.4 ind.l^{-1}, respectively) and there was no general pattern of *Artemia* abundance (Fig. 15).

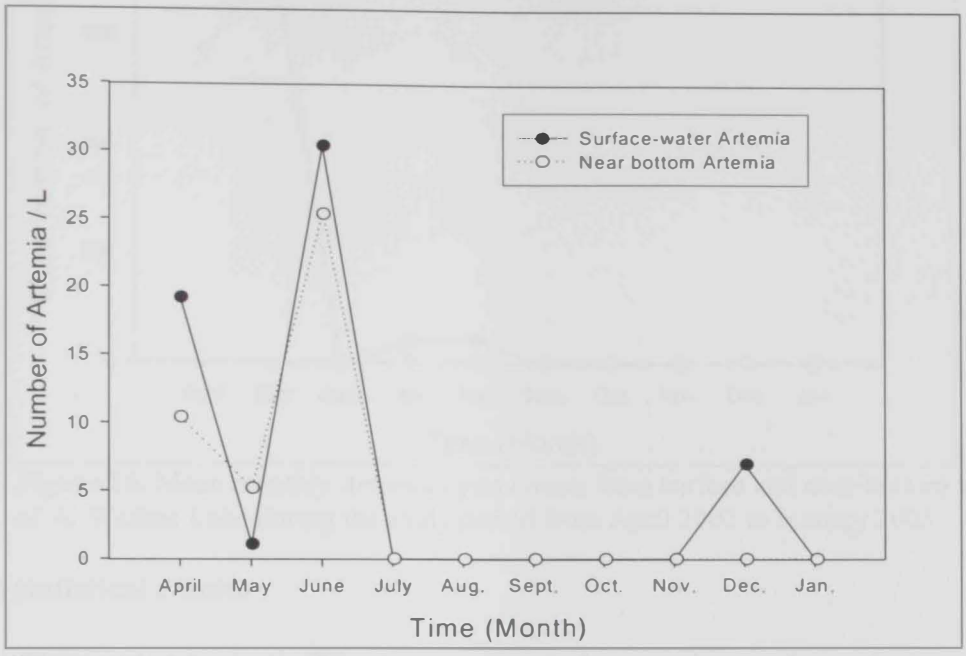

Figure 15. Mean monthly *Artemia* counts from surface and near-bottom waters of Al Wathba Lake during the study period from April 2002 to January 2003.

2.2. Artemia cysts

Artemia cysts were recorded from April through August in surface waters and from April through July in the near-bottom waters. However, no cysts were detected at any location or depth during June (Tables 23 & 24). The highest numbers were found in surface waters at site W5850 (4000 l^{-1}) in May and no *Artemia* cysts were found in several locations, while in deeper waters, the highest cyst numbers were detected at site W6146 in May and no cysts were found in several locations. In both surface and near-bottom waters, the greatest mean number of cysts was found in May (Fig.16)

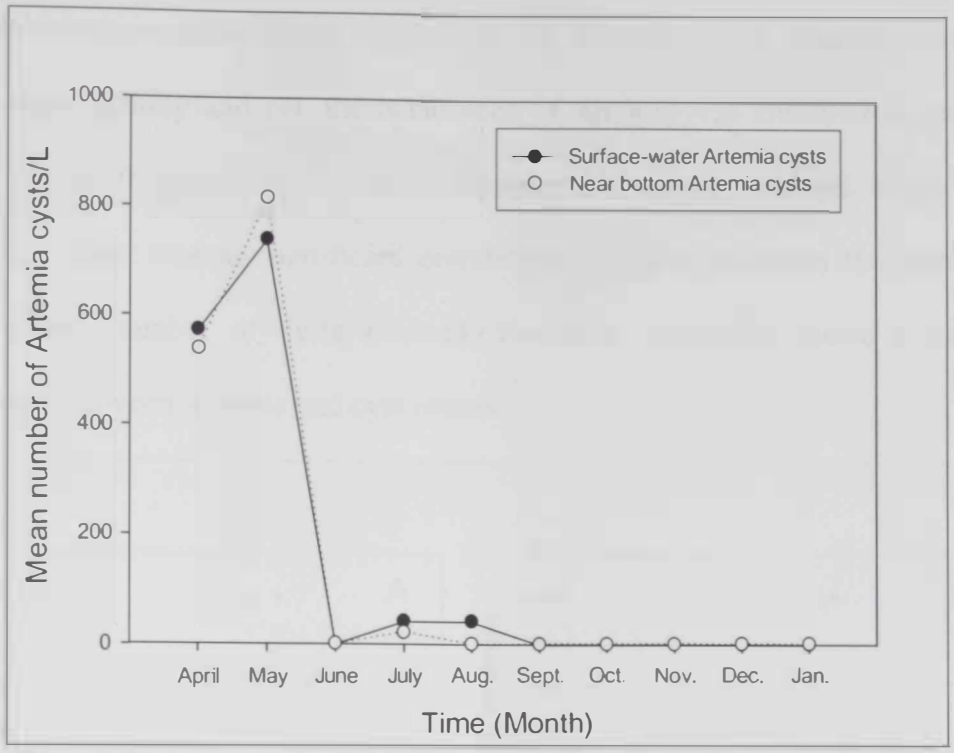

Figure 16. Mean monthly *Artemia* cysts counts from surface and near-bottom waters of Al Wathba Lake during the study period from April 2002 to January 2003.

3. The statistical results

3.1. The relationship between chemical and physical parameters and *Artemia* abundance in both surface and near-bottom samples.

A. Effect of physical factors

Although there was a significant correlation (P=0.0175) between the number of *Artemia* and lake water temperature (Table 25), the scatter plot of these two variables (Fig.17**A**) clearly shows that the correlation is heavily weighted by the absence of *Artemia* during many of the measurements. The significant correlation is therefore generated due to these 'zero' values, and there is no true correlation between these variables.

This pattern of significant correlations and 'zero' weighted scatter plots is repeated for number of *Artemia* versus Salinity (Fig.17**B**) and number of *Artemia* versus pH (Fig.17**C**), and the reasons for the apparent correlation are the same.

Although there were no linear patterns in the distribution of *Artemia* relative to temperature, salinity and pH, the occurrence of *Artemia* was clustered around (28-34°C), (140-170 ppt) and (7.5-8.4) for temperature, salinity and pH, respectively. Moreover, there was no significant correlation (P=0.118) between the number of *Artemia* and number of cysts counted. However, Fig.(17**D**) shows a negative correlation between *Artemia* and cyst counts.

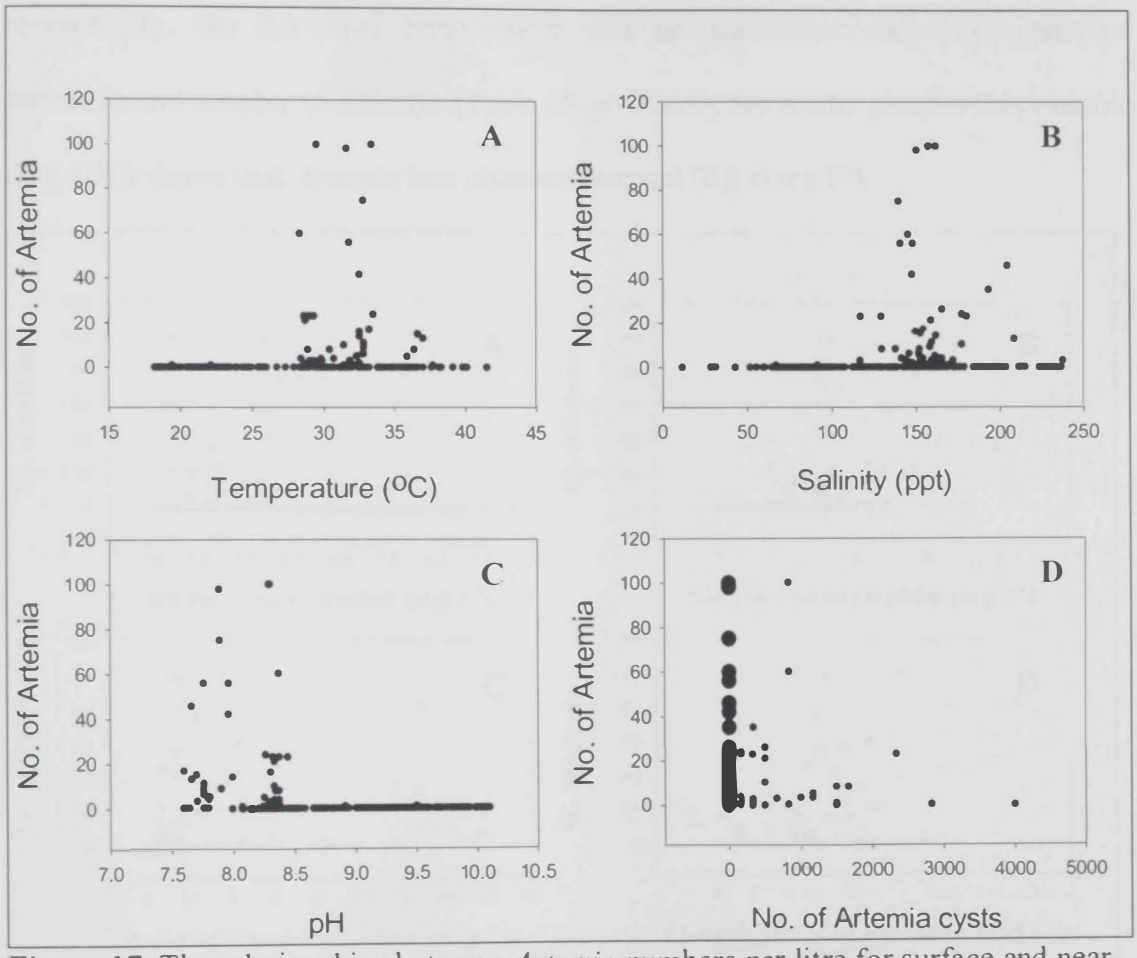

Figure 17. The relationships between *Artemia* numbers per litre for surface and near-bottom water samples and **A:** temperature, **B:** salinity, **C:** pH and **D:** number of *Artemia* cysts during the study.

B. Effect of chemical factors

There was a significant correlation between the number of *Artemia* and all the nutrients examined (P<0.05) (nitrate, nitrite, phosphate, calcium and magnesium), except for ammonia where P>0.05 (Table 25). The scatter plot of these five variables (Fig.18**A, B, D, E, F**) clearly shows that the correlation is also effected by the absence

of *Artemia* in many of the samples. The significant correlation is therefore generated due to these 'zero' values, and there is no true correlation between these variables. although there were no observed linear patterns in the distribution of *Artemia* relative to nitrate, nitrite, phosphate, calcium and magnesium, the occurrence of *Artemia* was clustered around (0.1-0.4 mg l^{-1}, (2-4 mg l^{-1}), (0.1-2 mg l^{-1}), (2500-3500 mg l^{-1}) and (3500-4700 mg l^{-1}) for nitrite, nitrate, phosphate, calcium and magnesium respectively. On the other hand, there was no significant correlation between ammonia and number of *Artemia* (Table 25, p=0.208), the scatter plot for this variable (Fig.18C) shows that *Artemia* was clustered around (0.1-6 mg l^{-1}).

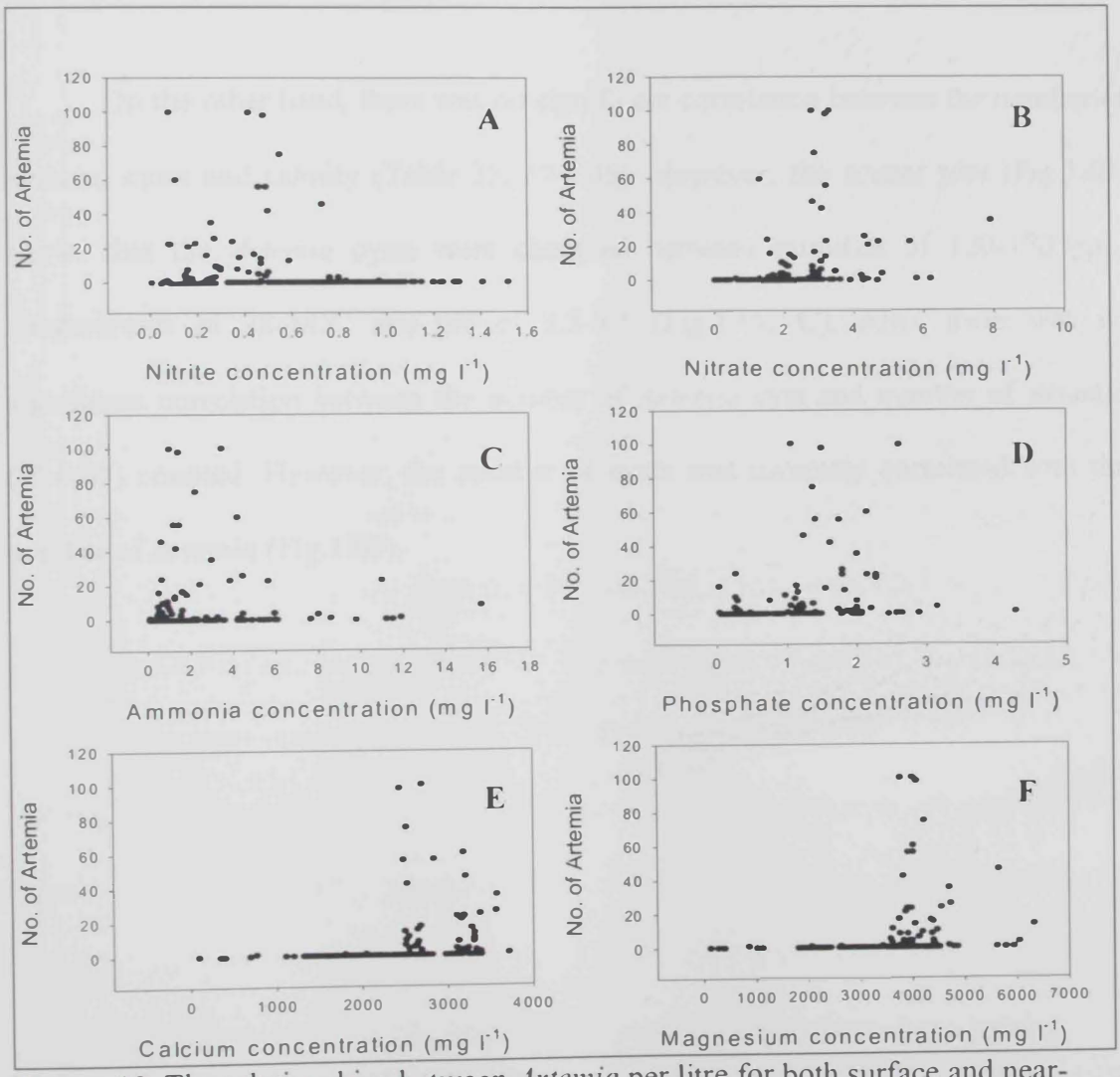

Figure 18. The relationships between *Artemia* per litre for both surface and near-bottom water samples and **A**: nitrite, **B**: nitrate, **C**: ammonia, **D**: phosphate, **E**: calcium and **F**: magnesium during the study.

3.2. The relationship between chemical and physical parameters and *Artemia* cysts abundance in both surface and near-bottom samples.

A. Effect of physical factors

There was a significant correlation between the number of cysts in the water samples and both water temperature and pH (Table 25). The scatter plot of these two variables (Fig.19**A**, **C**) clearly shows that this correlation is also effected by the absence of *Artemia* cysts during many of the samples. Therefore, this significant correlation is generated due to these 'zero' values, and there is no true correlation between these variables.

On the other hand, there was no significant correlation between the number of *Artemia* cysts and salinity (Table 25, $P>0.05$). However, the scatter plot (Fig.18**B**) shows that the *Artemia* cysts were clustered between salinities of 120-170 ppt., temperatures of 28-34°C and pH of 8.2-8.5 (Fig.19**A**, **C**). Also, there was no significant correlation between the number of *Artemia* cyst and number of *Artemia* ($P>0.05$) counted. However, the number of cysts was inversely correlated with the number of *Artemia* (Fig.19**D**).

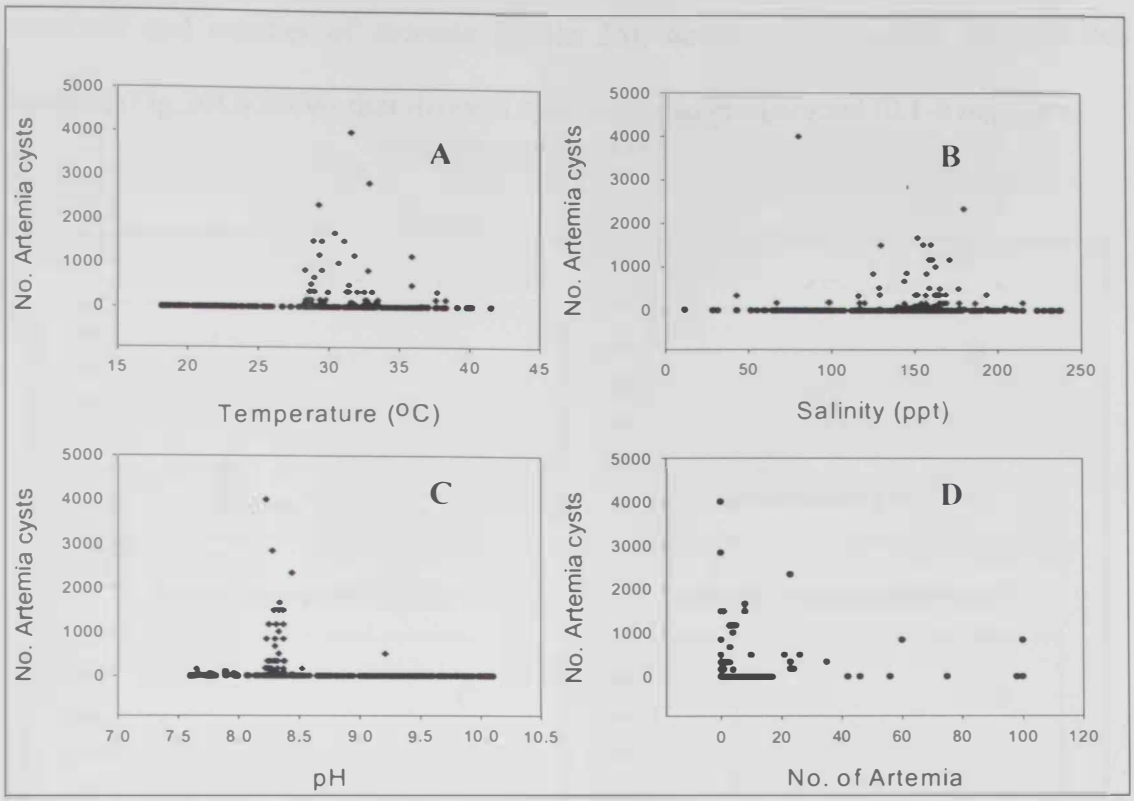

Figure 19. The relationships between number of *Artemia* cysts per litre for surface and near-bottom water samples and **A:** water temperature, **B:** salinity, **C**: pH and **D**: number of *Artemia* during the study.

B. Effect of chemical factors

There was a significant correlation ($P<0.05$) between the number of *Artemia* cysts and all the nutrients and minerals examined (nitrate, nitrite, phosphate, calcium and magnesium), except ammonia (Table 25). The scatter plots, of these five variables (Fig.20**A**, **B**, **D**, **E**, **F**) clearly show that the correlation is also affected by the absence of *Artemia* during many of the samples. The significant correlation is also generated due to these 'zero' values, and there is no true correlation between these variables. Although there were no observed linear patterns in the distribution of *Artemia* cysts relative to nitrate, nitrite, phosphate, calcium and magnesium, the occurrence of *Artemia* cysts were clustered around (0.1-1 mg l^{-1}, (1-5 mg l^{-1}), (0-2.5 mg l^{-1}), (3000-4000 mg l^{-1}) and (3800-4800 mg l^{-1}) for nitrite, nitrate, phosphate, calcium and magnesium, respectively. There was no significant correlation ($P>0.05$) between

ammonia and number of *Artemia* (Table 25), however, the scatter plot for this variable (Fig.20C) shows that *Artemia* cysts was clustered around (0.1-6 mg l^{-1}).

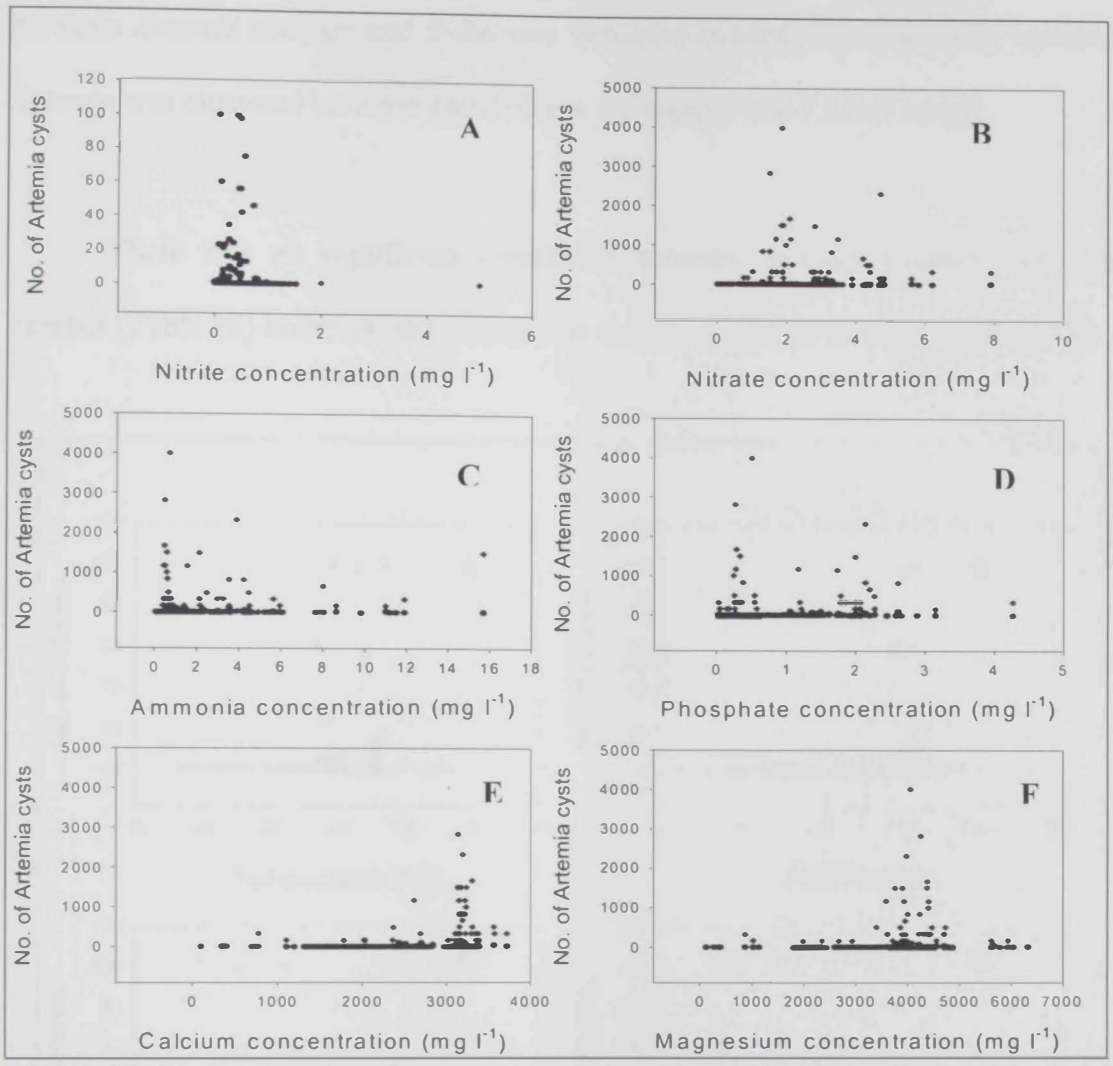

Figure 20. The relationships between *Artemia* cysts per litre for surface and near-bottom water samples and **A**: nitrite, **B**: nitrate, **C**: ammonia, **D**: phosphate, **E**: calcium and **F**: magnesium during the study.

3.4. The relationship between chemical and physical parameters and *Artemia* abundance in the surface water samples.

A. Effect of physical factors

There was a significant correlation between the number of *Artemia* in the surface samples and water temperature (Table 26). Although, there was no linear distribution pattern for *Artemia* number (Fig.21**A**), probably due to the effect of high

"zero" values that counted during sampling period, *Artemia* were clustered between temperatures of 27-34°C. This "zero" effect was also shown in the scatter plot for salinity and pH versus *Artemia* number (Fig.21**B, C**) where a significant correlation between *Artemia* number and those two variables existed. For those two variables, *Artemia* was clustered between 140-160 ppt for salinity and 7.5-8.5 for pH.

There was no significant correlation between *Artemia* numbers and cysts number (Table 26) however; the scatter plot shows a negative correlation (Fig21**D**).

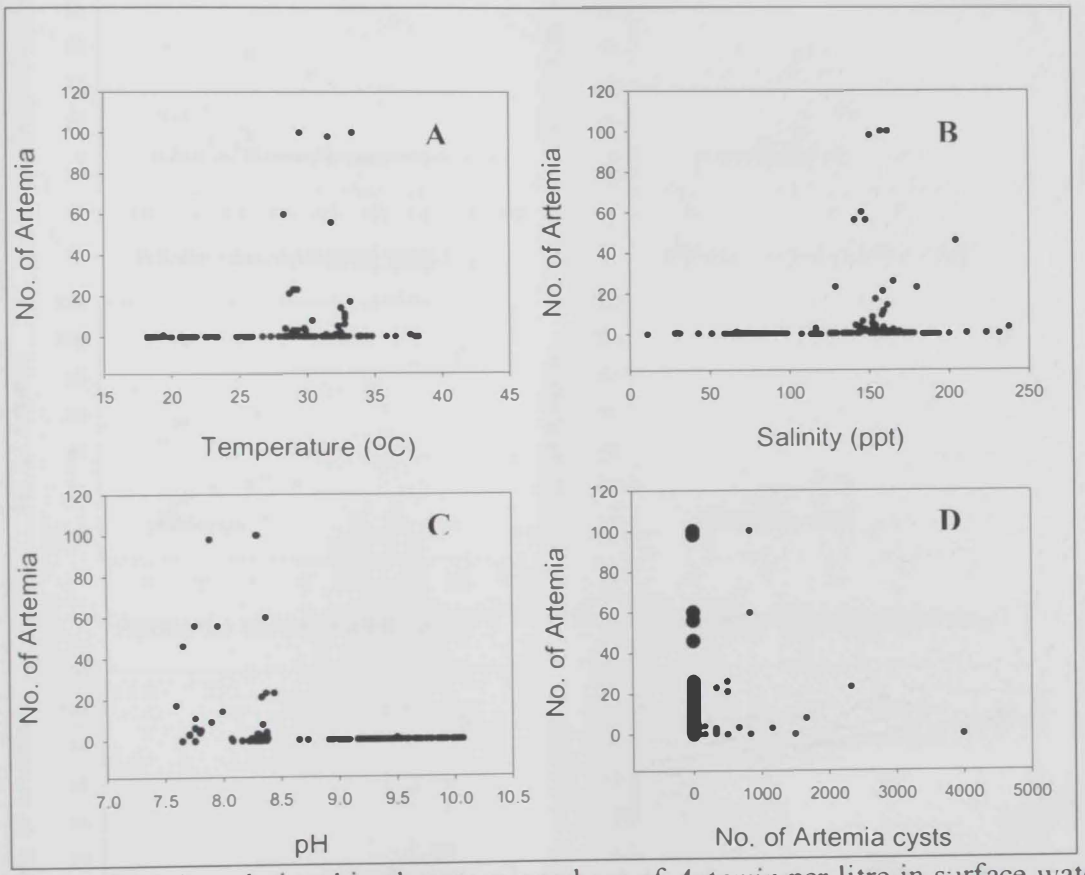

Figure 21. The relationships between numbers of *Artemia* per litre in surface water samples and **A:** temperature, **B:** salinity, **C:** pH and **D:** number of *Artemia* cysts during the study.

B. Effect of Chemical factors

There was a significant correlation between *Artemia* number in the surface samples and nitrite, nitrate, ammonia, phosphate, calcium and magnesium (Table 26).

There was no linear pattern in the scatter plot for the *Artemia* distribution (Fig.22A, B, C, D, E, F), which was caused by the large number of zero counts during the sampling period. Therefore, this significant correlation is not considered to be true. However, *Artemia* was clustered between (0.1-0.5 mg l^{-1}), (2-4 mg l^{-1}), (0.1-4 mg l^{-1}), (1-2 mg l^{-1}), (2500-3500 mg l^{-1}) and (3500-4500 mg l^{-1}) for nitrite, nitrate, ammonia, phosphate, calcium and magnesium, respectively.

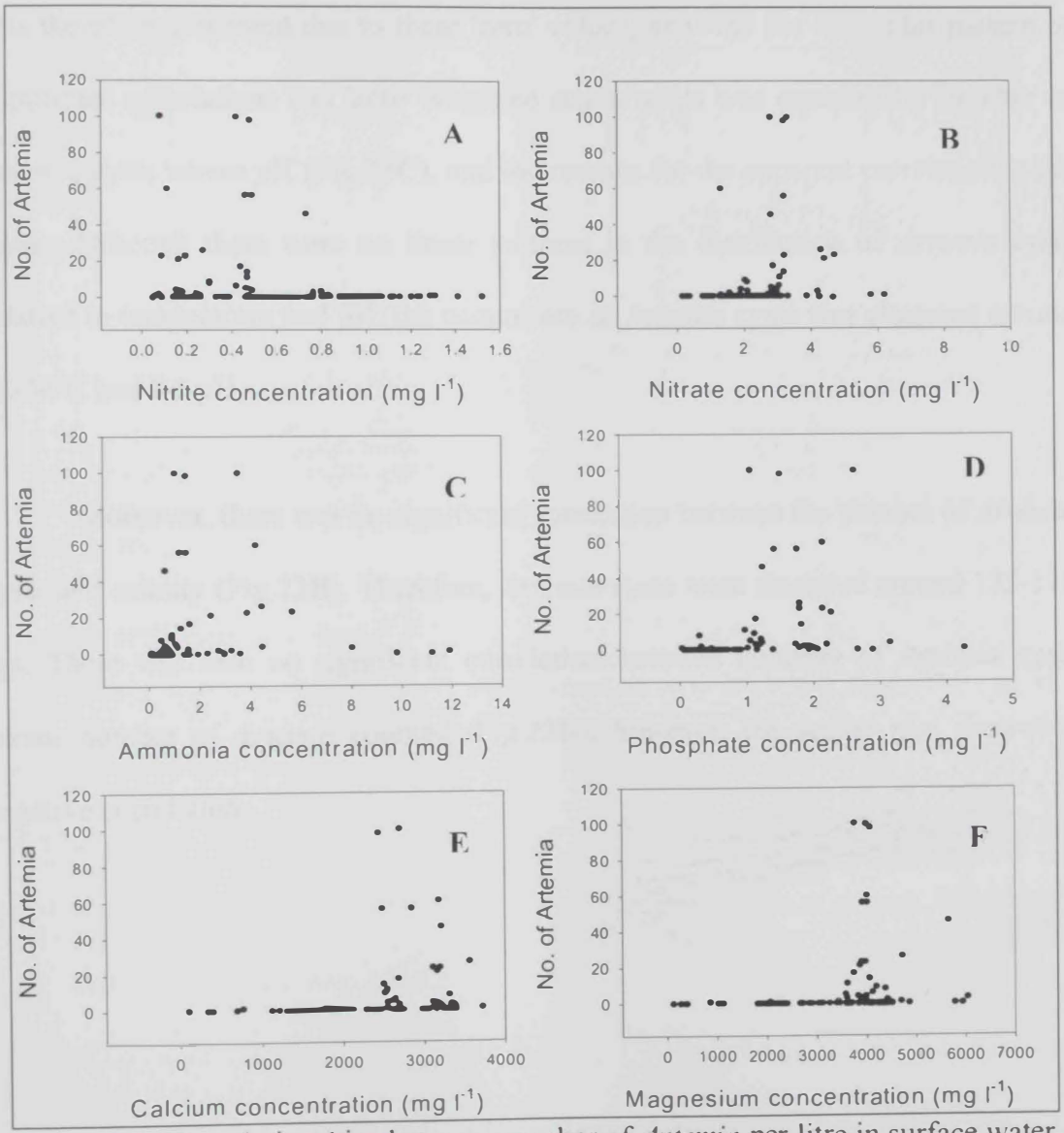

Figure 22. The relationships between number of *Artemia* per litre in surface water samples and **A:** nitrite, **B:** nitrate, **C:** ammonia, **D:** phosphate, **E:** calcium and **F:** magnesium during the study.

3.5. The relationship between chemical and physical parameters and *Artemia* cysts abundance in the surface samples.

A. Effect of physical factors

There was a significant correlation between the number of cysts *Artemia* and lake water temperature in the surface samples (Table 26). Meanwhile, the scatter plot of these two variables clearly shows that this correlation is strongly affected by the absence of *Artemia* cysts in most of the samples (Fig.23**A**). Te significant correlation was therefore generated due to these 'zero' values, and was not true. This pattern of significant correlations and 'zero' weighted scatter plots was repeated for number of *Artemia* cysts versus pH (Fig.23**C**), and the reasons for the apparent correlation is the same. Although there were no linear patterns in the distribution of *Artemia* cysts relative to temperature and pH, the occurrence of *Artemia* cysts was clustered around 28-34°C and 8.2 pH.

Moreover, there was no significant correlation between the number of *Artemia* cysts and salinity (Fig.23**B**). Therefore, *Artemia* cysts were clustered around 125-175 ppt. There was also no significant correlation between numbers of *Artemia* cysts versus number of *Artemia* counted (Fig.23**D**), however, the scatter plot showed a negative correlation.

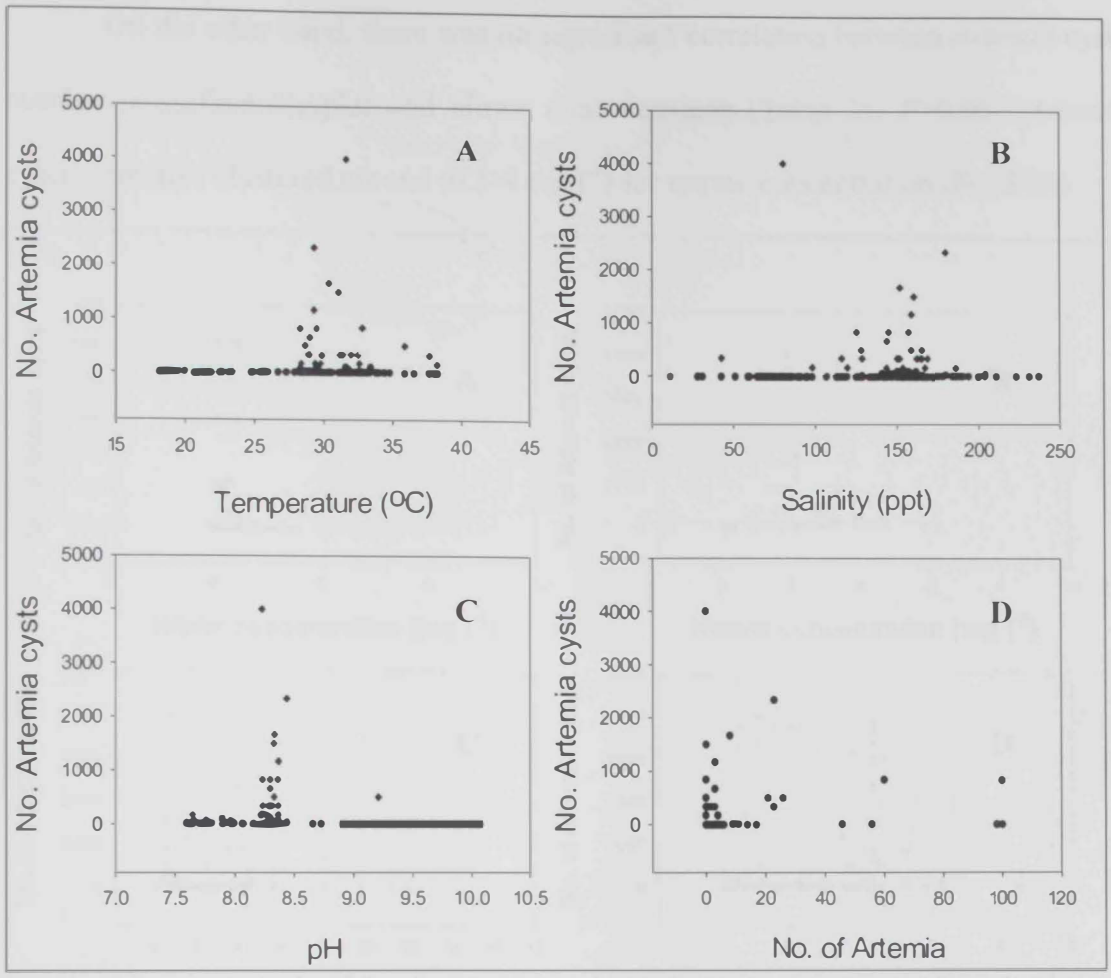

Figure 23. The relationships between number of *Artemia* cysts per litre in surface water samples and **A:** water temperature, **B:** Salinity, **C:** pH and **D:** number of *Artemia* during the study.

B. Effect of chemical factors

There was a significant correlation between *Artemia* cysts in surface samples versus nitrite, ammonia, phosphate, calcium and magnesium (Table 26, $P<0.05$). This correlation may not be true because of the effect of "zero" values that have been counted during the measurements. However, there was no linear pattern for *Artemia* cysts distribution, but the values of nitrite, ammonia, phosphate, calcium and magnesium were clustered around (0.1-0.5 mg l^{-1}), (0.1-4 mg l^{-1}), (0.1-2.5 mg l^{-1}), (3100-3500 mg l^{-1}) and (4000-4800 mg l^{-1}), respectively (Fig.24**A, C, D, E, F**).

On the other hand, there was no significant correlation between *Artemia* cysts number in surface samples and nitrate concentrations (Table 26, $P>0.05$). *Artemia* cysts were also clustered around (0.1-4 mg l^{-1}) for nitrate concentration (Fig.24B).

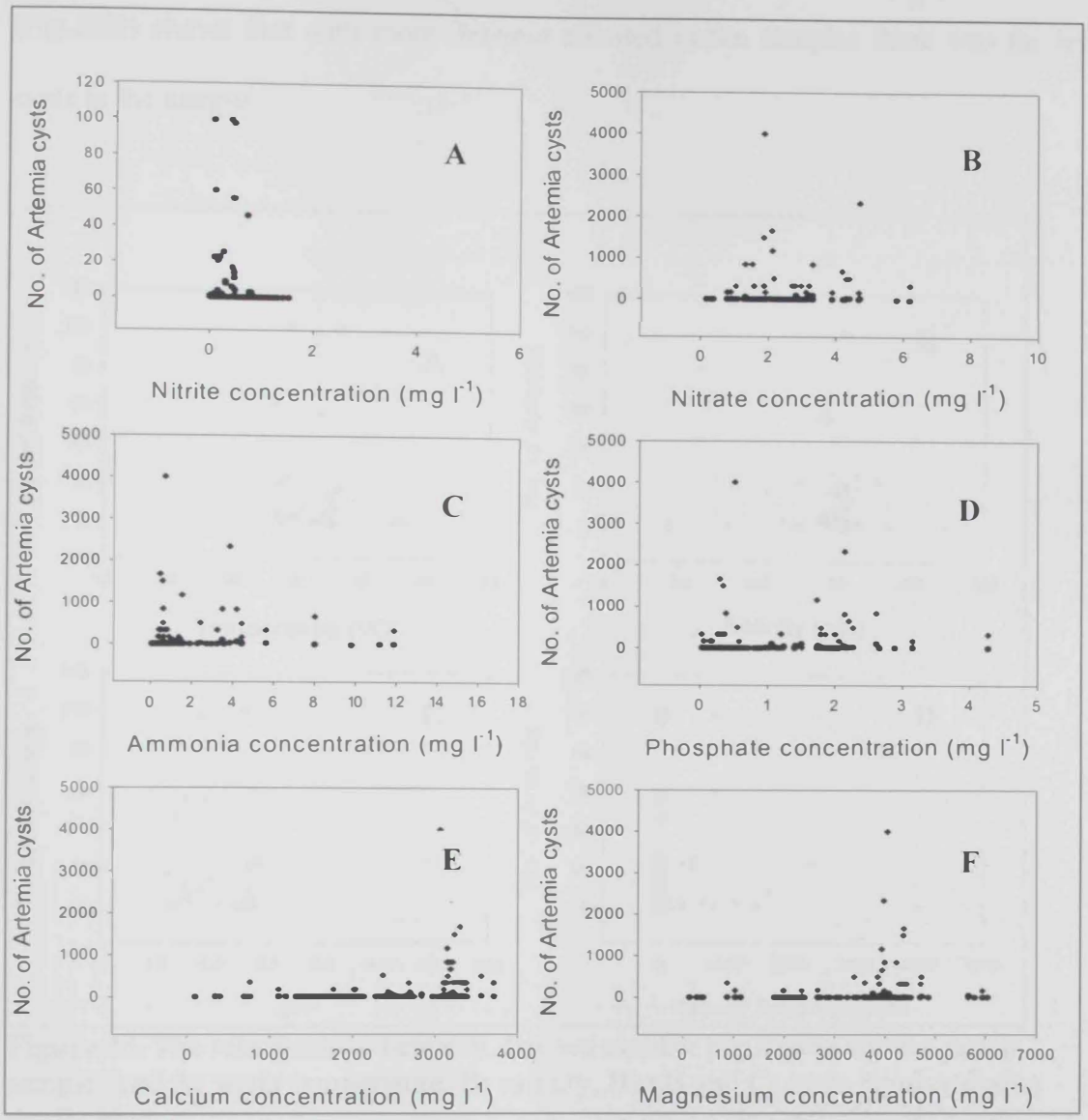

Figure 24. The relationships between number of *Artemia* cysts per litre in surface water samples and **A:** nitrite, **B:** nitrate, **C:** ammonia, **D:** phosphate, **E:** calcium and **F:** magnesium during the study.

3.6. The relationship between physical and chemical parameters and *Artemia* abundance in surface water samples during April - June.

A. Effect of physical factors

There was no significant correlation between *Artemia* number in surface samples during April, May and June versus water temperature, salinity, pH and cysts

number (Table 27, $P>0.05$). Although, there is no linear pattern in the scatter plot for these variables (Fig.24**A**, **B**, **C**), *Artemia* number were clustered around (27-34°C), (140-170ppt), (7.5-8.4) for water temperature, salinity and pH respectively. Moreover, (Fig.25**D**) shows that with more *Artemia* counted in the samples there was far less cysts in the sample.

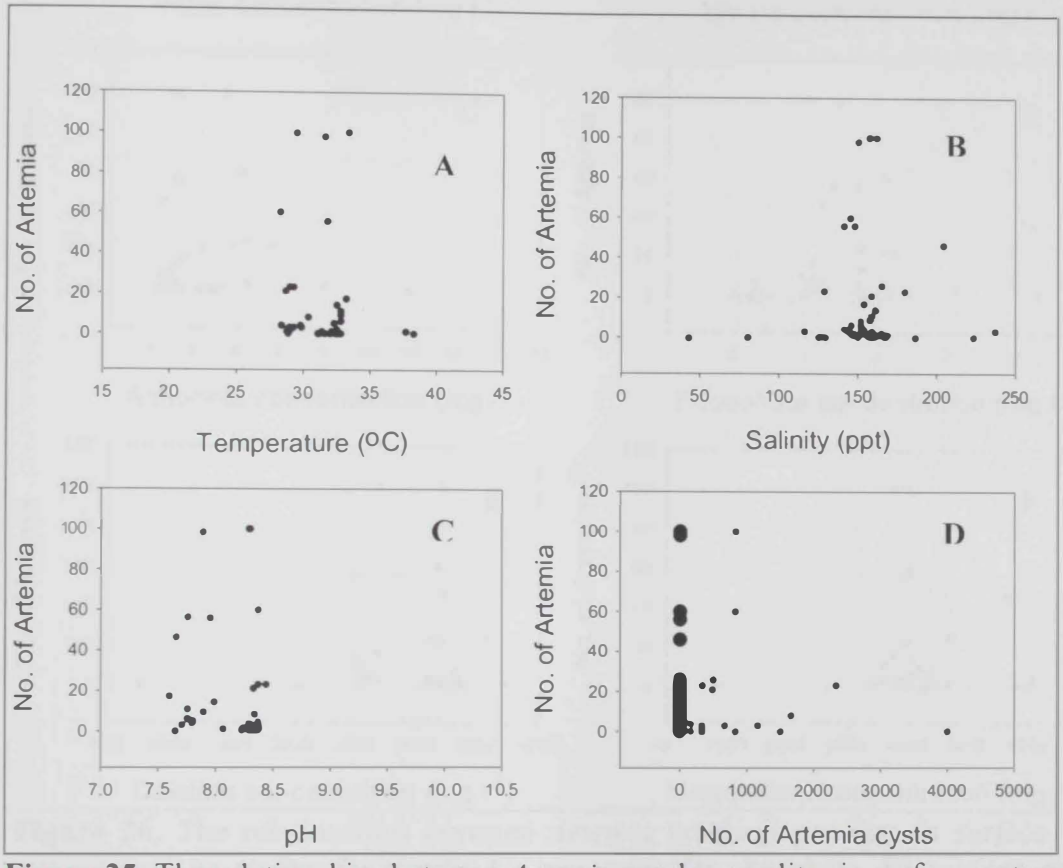

Figure 25. The relationships between *Artemia* number per litre in surface water samples and **A:** water temperature, **B:** salinity, **D:** pH and **C:** cysts number during April- June.

B. Effect of chemical factors

There was no significant correlation between *Artemia* numbers in the surface samples versus nitrite, nitrate, ammonia, phosphate, calcium and magnesium (Table 27, $P>0.05$). This weak correlation is shown clearly in the scatter plot for these variables (Fig.26**A**, **B**, **C**, **D**, **E**, **F**).

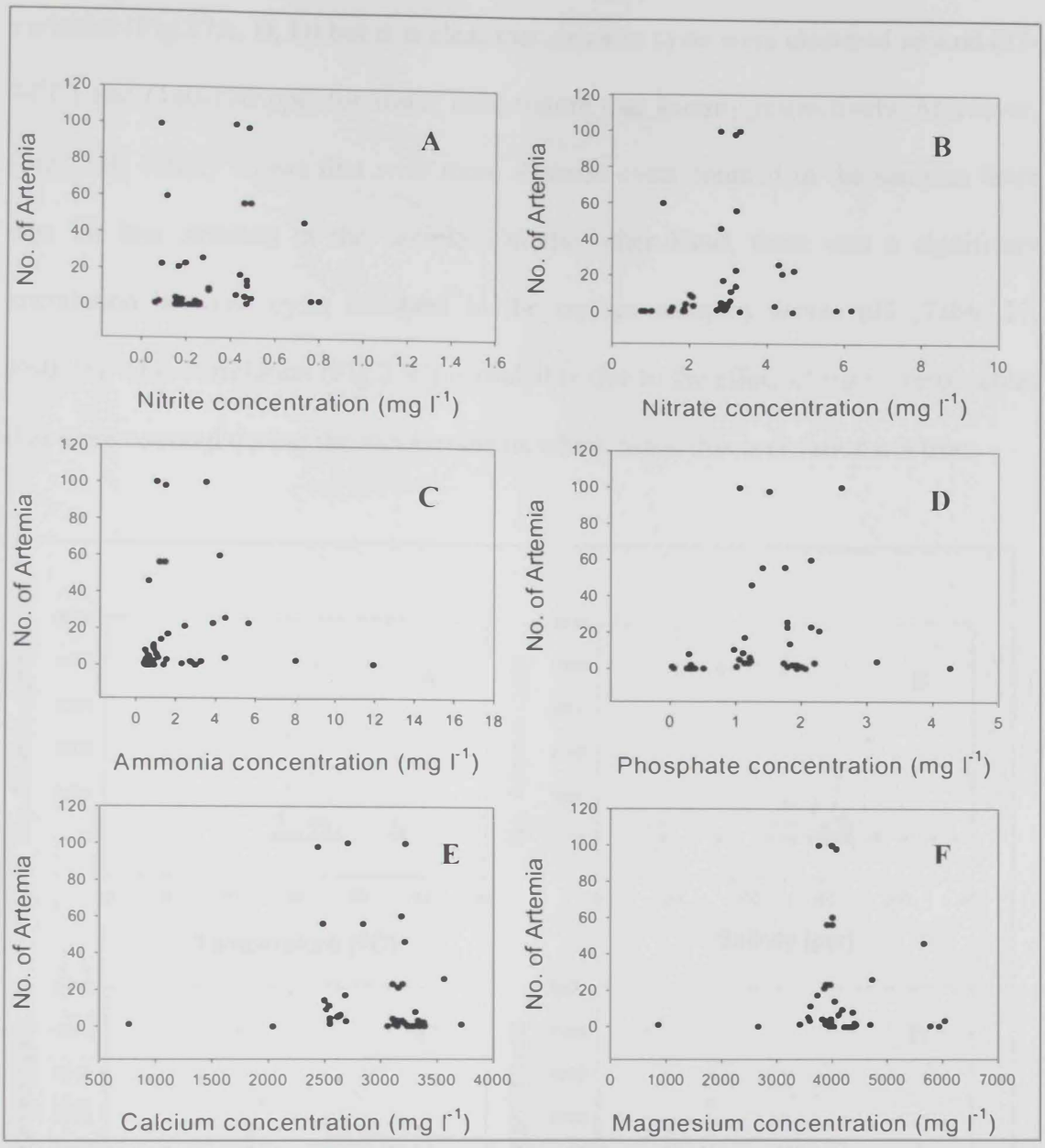

Figure 26. The relationships between *Artemia* numbers per litre in surface water samples and **A:** nitrite, **B:** nitrate, **C:** ammonia, **D:** phosphate, **E:** calcium and **F:** magnesium during April- June.

3.7. The relationship between the physical and chemical parameters and *Artemia* cysts abundance in surface samples during April - June.

Physical factors

There was no significant correlation between *Artemia* cysts number in surface samples during April-June versus water temperature, salinity, and *Artemia* numbers (Table 27, $P>0.05$). Although, there is no linear pattern in the scatter plot for these

variables (Fig.27**A**, **B**, **D**) but it is clear that *Artemia* cysts were clustered around (27-34°C) and (140-170 ppt) for water temperature and salinity respectively. Moreover, (Fig.27**D**) clearly shows that with more *Artemia* cysts counted in the samples there was far less *Artemia* in the sample. On the other hand, there was a significant correlation between cysts numbers in the surface samples versus pH (Table 27, $P<0.05$). This correlation (Fig.27**C**) is probably due to the effect of many 'zero' values that were counted during the measurements which made this correlation not true.

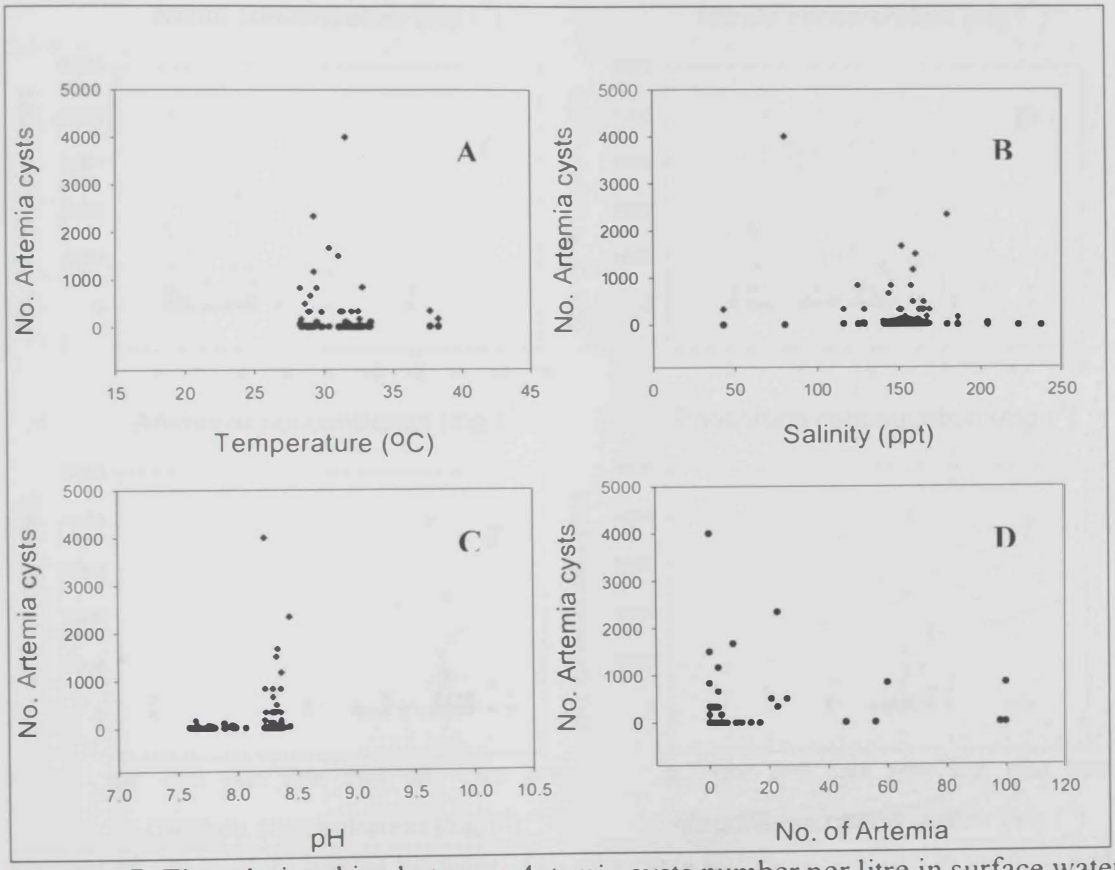

Figure 27. The relationships between *Artemia* cysts number per litre in surface water samples and **A:** water temperature, **B:** salinity, **D:** pH and **C:** cysts number during April-June.

B. Effect of chemical factors

There was no significant correlation found between *Artemia* cysts numbers in the surface samples versus nitrite, nitrate, ammonia, phosphate, calcium and

magnesium (Table 27, $P>0.05$). This weak correlation is shown clearly in the scatter plot for these variables (Fig.28**A, B, C, D, E, F**).

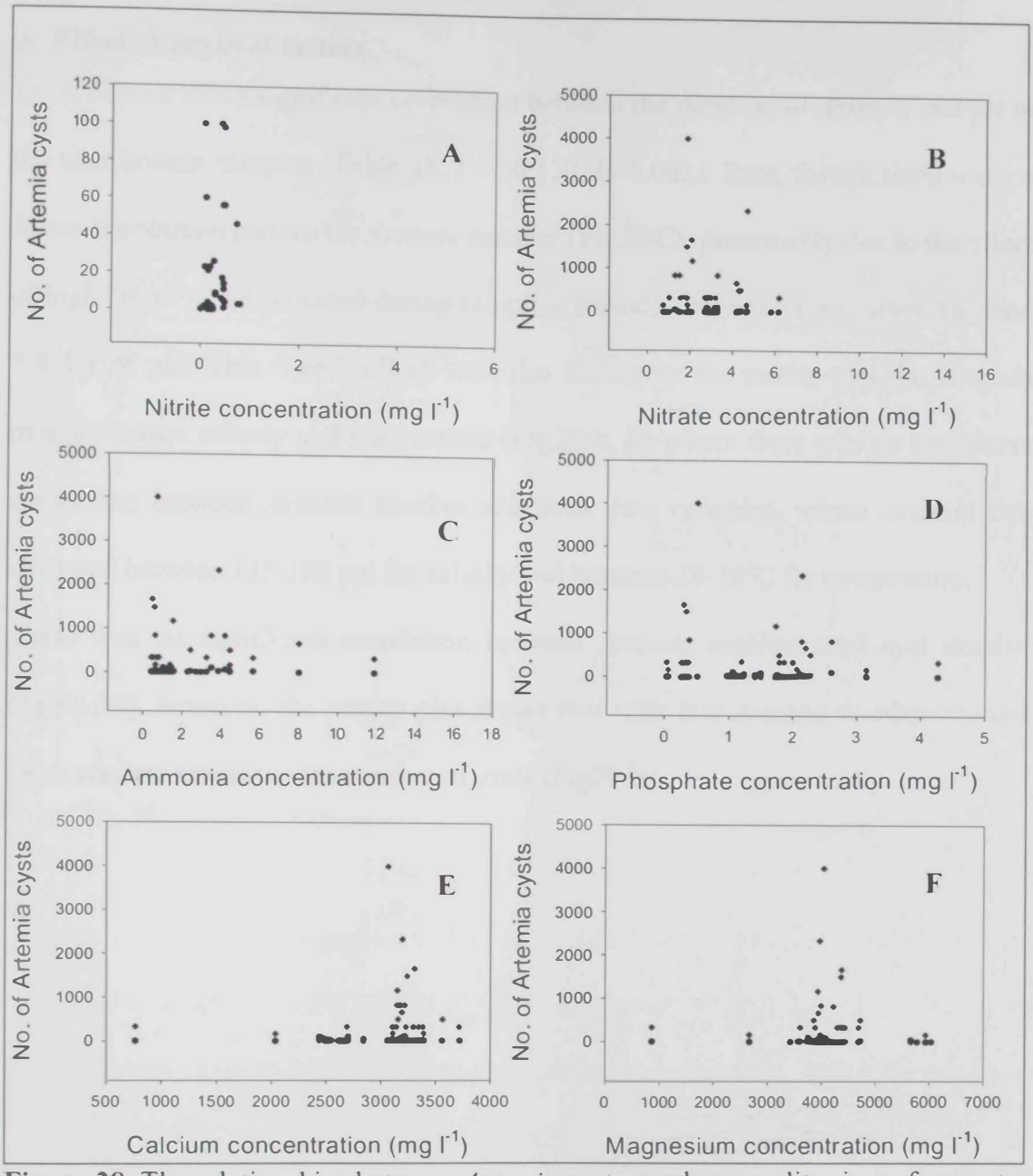

Figure 28. The relationships between *Artemia* cysts numbers per litre in surface water samples and **A:** nitrite, **B:** nitrate, **C:** ammonia, **D:** phosphate, **E:** calcium and **F:** magnesium during April-June.

3.8. The relationship between chemical and physical parameters and *Artemia* abundance in near-bottom water samples.

A. Effect of physical factors

There was a significant correlation between the numbers of *Artemia* and pH in the near-bottom samples (Table 28, r = -0.330, P>0.002). Even though there was no linear distribution pattern for *Artemia* number (Fig.29**C**), presumably due to the effect of high "zero" values counted during sampling period, *Artemia* were clustered around 7.8-8.4 of pH. This "zero" effect was also shown in the scatter plot for *Artemia* number versus salinity and temperature (Fig.29**A, B**) where there was no significant correlation between *Artemia* number and those two variables, where *Artemia* was clustered between 125-180 ppt for salinity and between 28-36°C for temperature.

There was no significant correlation between *Artemia* numbers and cyst number (Table 28), however, the scatter plot shows that with less *Artemia* number counted there was an increase in the number of cysts (Fig29.**D**).

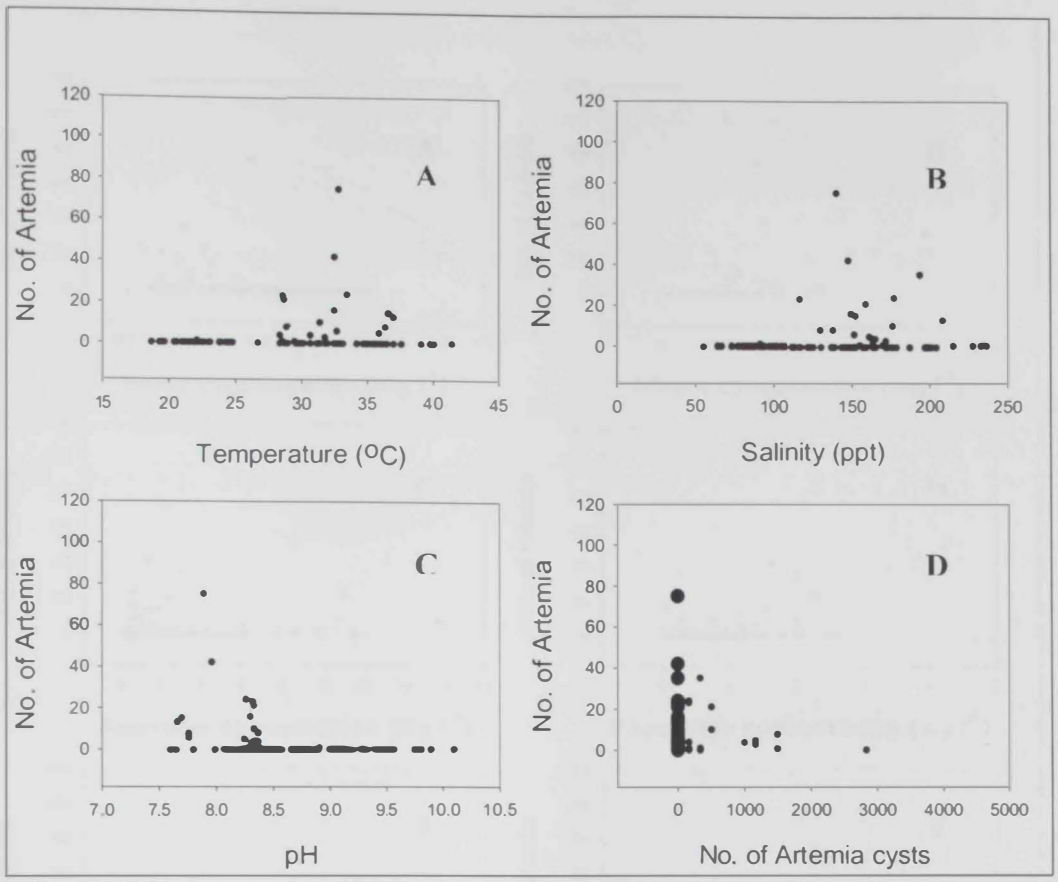

Figure 29. The relationships between the numbers of *Artemia* per litre in near-bottom samples and **A**: water temperature, **B**: salinity, **C**: pH and **D**: number of *Artemia* cysts during the study.

B. Effect of chemical factors

There was a significant correlation between *Artemia* number in near-bottom samples and nitrate, phosphate, calcium and magnesium (Table 28). However, there was no linear pattern in the scatter plot for the *Artemia* distribution (Fig.30**B**, **D**, **E**, **F**), which may have been due to the large number of zero counts during the sampling period. Therefore, this significant correlation is not considered to be true correlation. However, *Artemia* was clustered between (1.8-4 mg l^{-1}), (0-2.5 mg l^{-1}), (2500-3400 mg l^{-1}) and (3500-4700 mg l^{-1}) for nitrate, phosphate, calcium and magnesium respectively. Moreover, there was no significant correlation found between number of *Artemia* numbers in near bottom samples versus nitrite and ammonia (Table 28). *Artemia* numbers were clustered around (0.1-0.6 mg l^{-1}) and (0-3 mg l^{-1}) for nitrite and ammonia, respectively (Fig.30**A**, **C**).

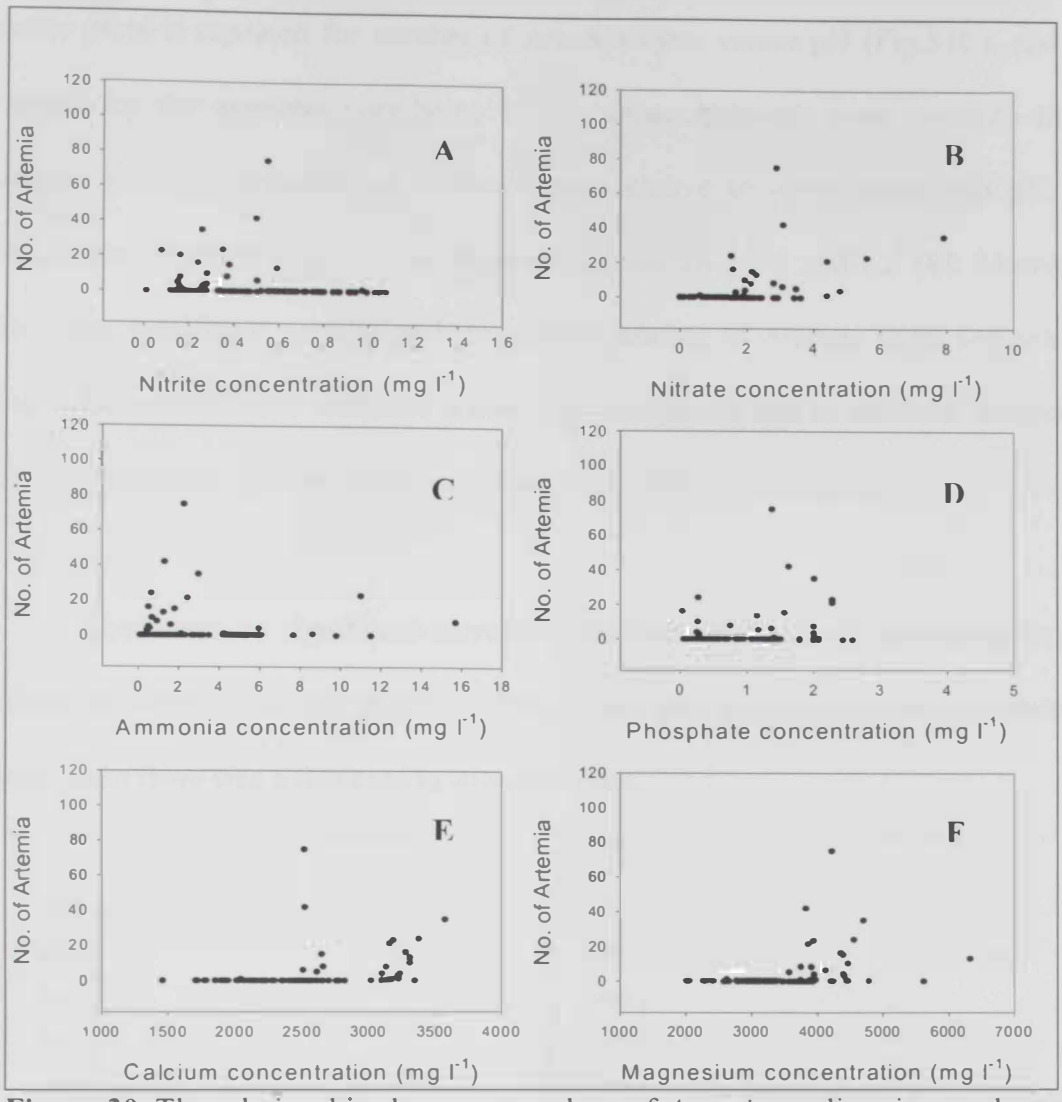

Figure 30. The relationships between numbers of *Artemia* per litre in near-bottom samples and **A:** nitrite, **B:** nitrate, **C:** ammonia, **D:** phosphate, **E:** calcium and **F:** magnesium during the study.

3.9. The relationship between chemical and physical parameters and *Artemia* cysts abundance in near-bottom samples.

A. Effect of physical factors

There was a significant correlation between the number of *Artemia* cysts and near bottom water temperature in the samples (Table 28). However, the scatter plot of these two variables clearly shows that the correlation is strongly affected by the absence of *Artemia* cysts during many samples (Fig.31A). The significant correlation is therefore generated due to these 'zero' values, and there is no true correlation between these variables. This pattern of significant correlations and 'zero' weighted

scatter plots is repeated for number of *Artemia* cysts versus pH (Fig.31C), and the reasons for the apparent correlation is the same. Although there were no linear patterns in the distribution of *Artemia* cysts relative to temperature, and pH, the occurrence of *Artemia* cysts was clustered around 28-34°C and 8.2 pH. Moreover, there was significant correlation between the number of *Artemia* cysts and salinity (Fig.31B) and the 'zero' weighted scatter plot is repeated due to the same mentioned reason, therefore, *Artemia* cysts was clustered around 160-200 ppt.

There was no significant correlation between numbers of *Artemia* cysts and number of *Artemia* counted (Fig.31D). The scatter plot shows that with more *Artemia* cysts count there was a decrease in *Artemia* count.

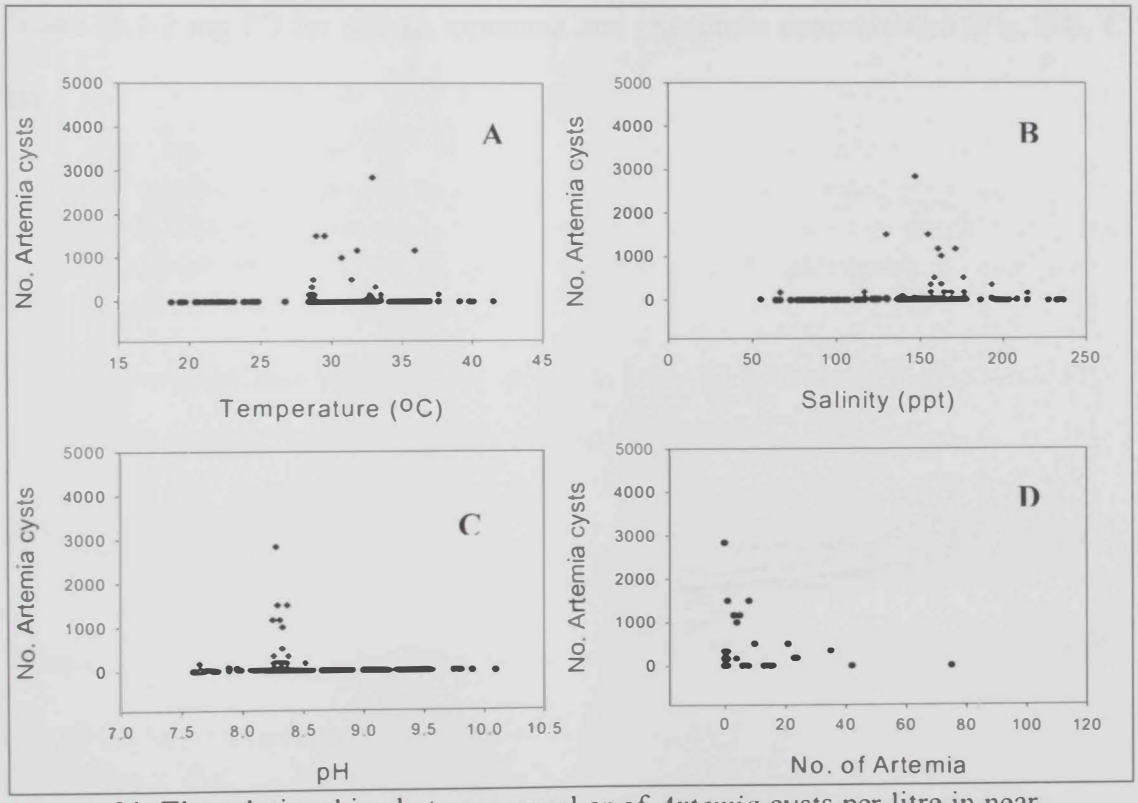

Figure 31. The relationships between number of *Artemia* cysts per litre in near-bottom samples and **A:** water temperature, **B:** salinity, **C:** pH and **D:** number of *Artemia* during the study.

B. Chemical factors

There was a significant correlation between *Artemia* cysts numbers in near bottom samples and nitrite, calcium and magnesium (Table 28, $P<0.05$). This correlation may not be true, because of the effect of "zero" values that have been counted during the measurements. However, there was no linear pattern for *Artemia* cysts distribution but they were clustered around (0.1-1 mg l^{-1}), (3000-3500 gm/l) and (3800-4800 mg l^{-1}) for nitrite, calcium and magnesium respectively (Fig.32**A**, **E**, **F**).

On the other hand, there was no significant correlation between *Artemia* cysts number in near bottom samples versus nitrate, ammonia and phosphate concentrations (Table 28, $P>0.05$). *Artemia* cysts was also clustered around (1-4 mg l^{-1}), (0.1-4 mg l^{-1}) and (0.1-2 mg l^{-1}) for nitrate, ammonia and phosphate concentration (Fig.32**B**, **C**, **D**).

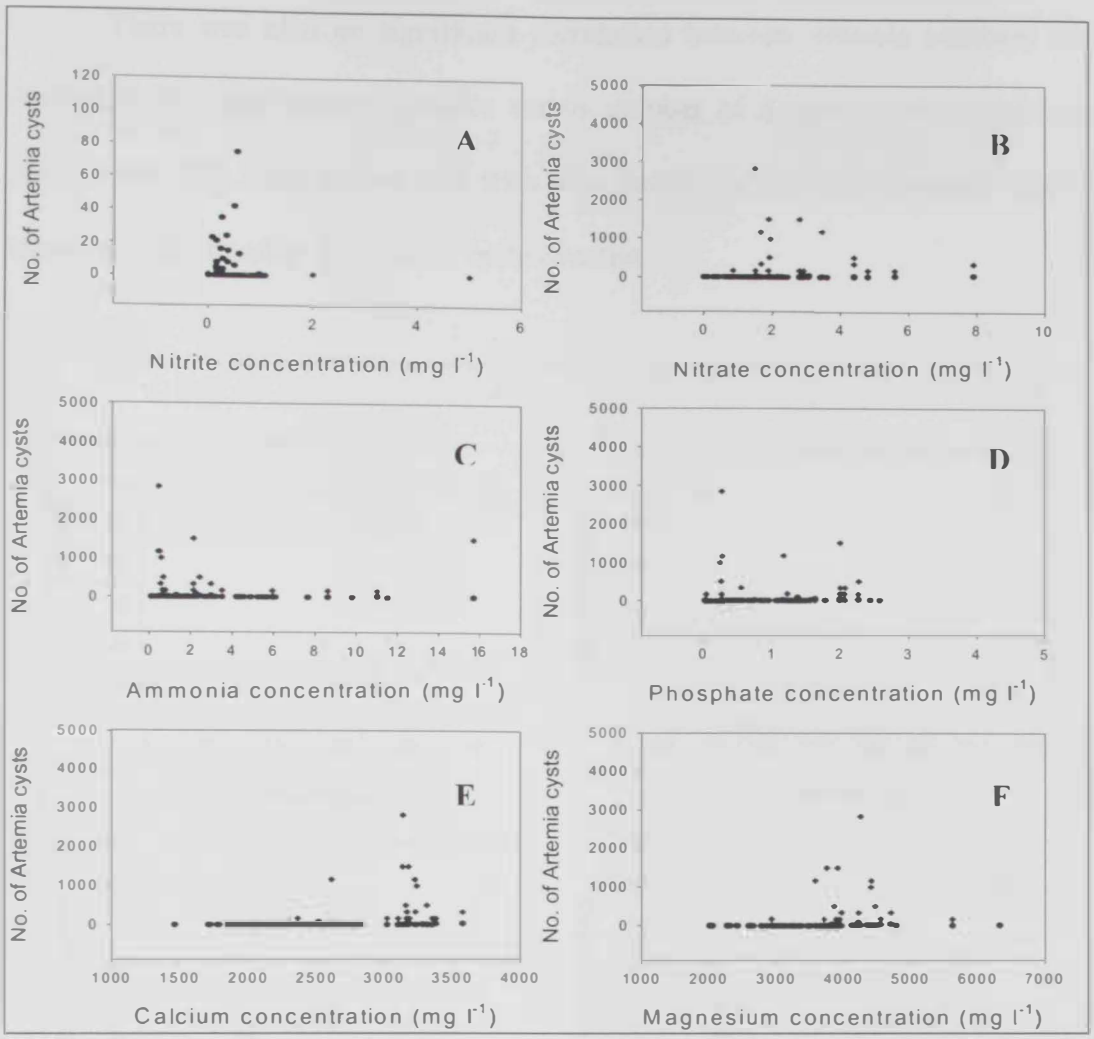

Figure 32. The relationships between number of *Artemia* cysts per litre in near-bottom samples and **A:** nitrite, **B:** nitrate, **C:** ammonia, **D:** phosphate, **E:** calcium and **F:** magnesium during the study.

3.10. The relationship between physical and chemical parameters and *Artemia* abundance in near-bottom samples during April - June.

A. Effect of physical factors

There was no significant correlation between the number of *Artemia* in near-bottom samples during April-June versus water temperature, salinity and pH (Table 29, $P>0.05$). However,, the scatter plot (Fig.33**A**, **B**, **C**) clearly shows that *Artemia* numbers were clustered around (27-37°C), (140-170 ppt) and (8.3-8.4) for water temperature, salinity and pH respectively.

There was also no significant correlation between *Artemia* numbers during April-June for near-bottom samples versus number of *Artemia* cysts, however, the scatter plot (Fig.33**D**) shows that with less number of *Artemia* counted there was increase in the number of *Artemia* cysts counted.

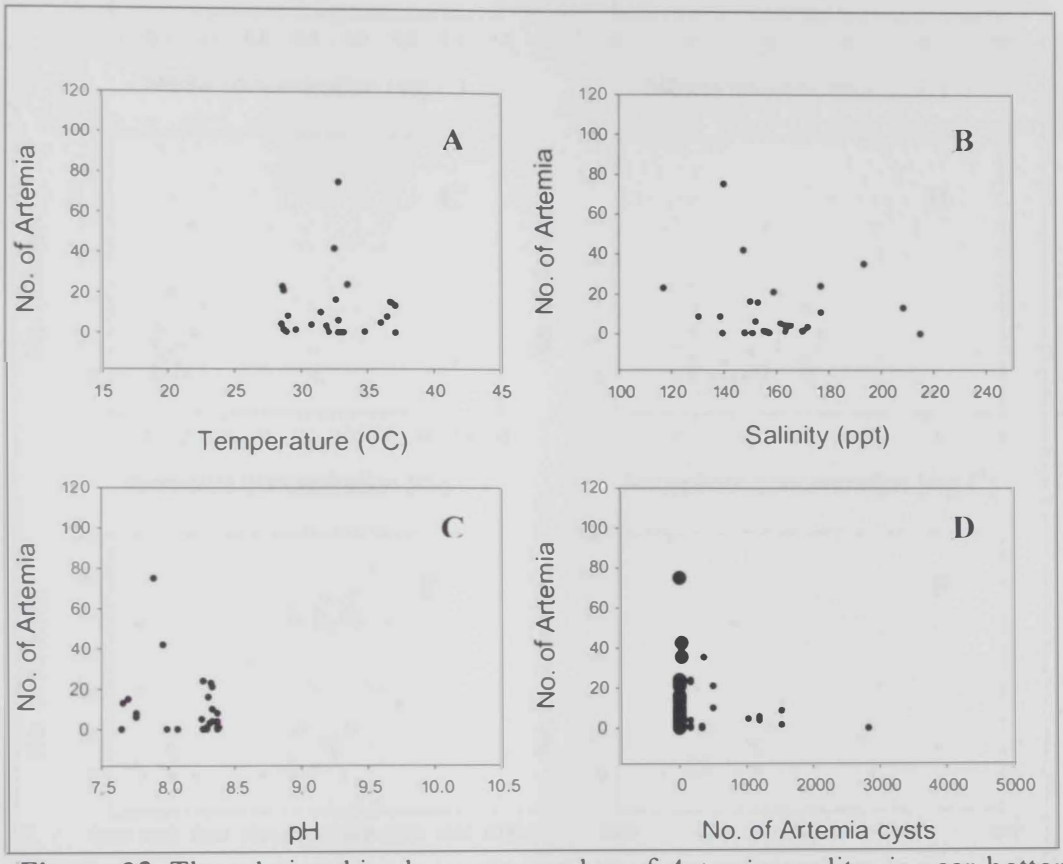

Figure 33. The relationships between number of *Artemia* per litre in near-bottom water samples and **A:** temperature, **B:** salinity, **C:** pH and **D:** *Artemia* cysts number during April- June.

B. Effect of chemical factors

There was no significant correlation between *Artemia* number in near-bottom samples during April-June versus nitrite, nitrate, ammonia, phosphate, calcium and magnesium (Table 29). It is shown clearly in the scatter plot (Fig.34**A, B, C, D, E, F**) that there is no linear pattern for the distribution of *Artemia* numbers during the specified months versus mentioned variables ($P>0.05$). Therefore, *Artemia* numbers were distributed among large scale of concentrations.

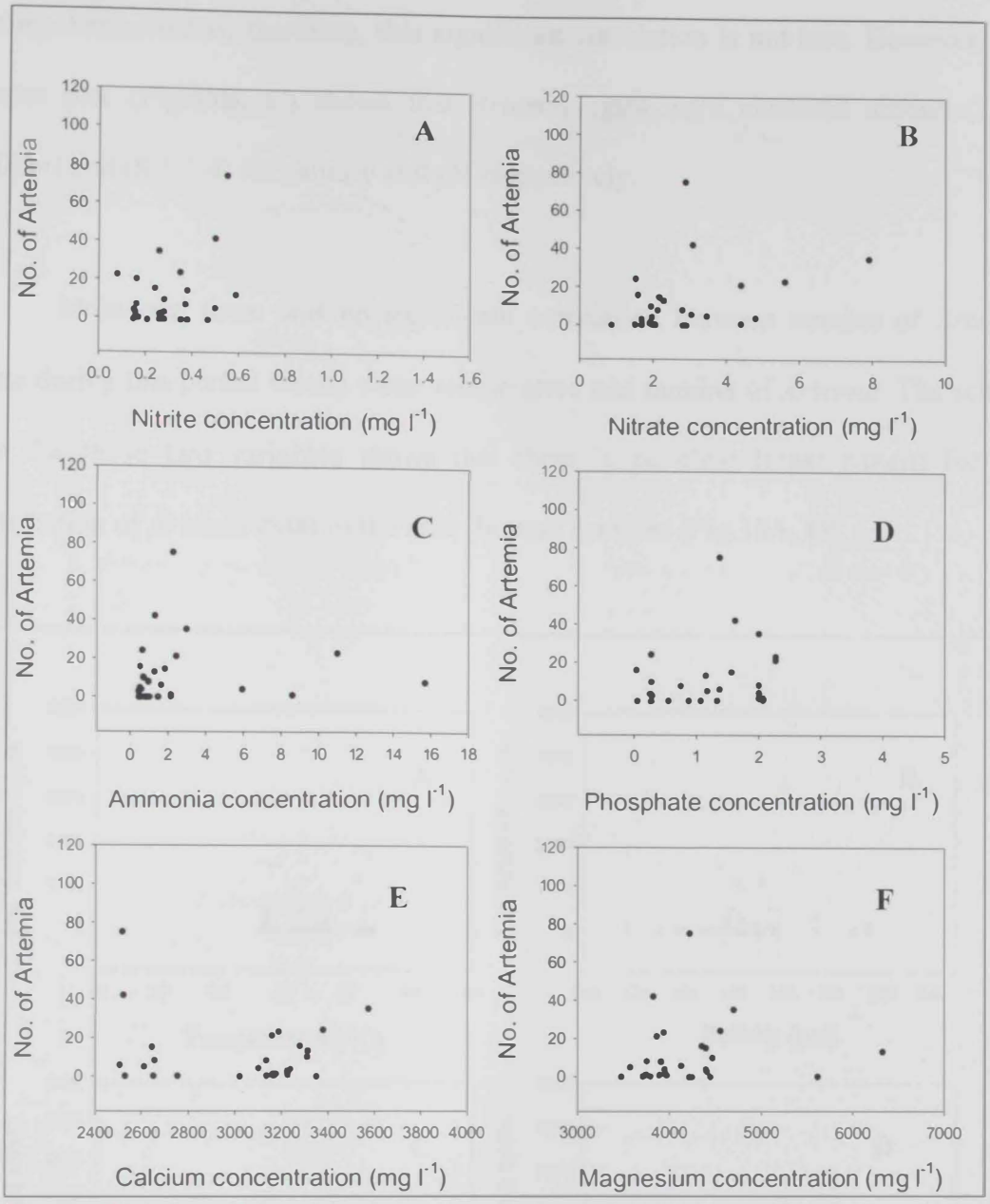

Figure 34. The relationships between number of *Artemia* per litre in near-bottom water samples and **A:** nitrite, **B:** nitrate **C:** ammonia and **D:** phosphate, **E:** calcium and **F:**magnesium during April-June.

3.11. The relationship between the physical and chemical parameters and *Artemia* cysts abundance in near-bottom samples during April - June.

A. Effect of physical factors

There was a significant correlation between number of *Artemia* cysts in near-bottom samples during April-June versus salinity and pH (Table 29). However, this correlation was strongly affected by the large number of 'zero' that was counted

during these months; therefore, this significant correlation is not true. However, the scatter plot (Fig.35**B, C**) shows that *Artemia* cysts were clustered around (150-170ppt) and (8.3-8.4) for salinity and pH respectively.

Moreover, there was no significant correlation between number of *Artemia* cysts during this period versus water temperature and number of *Artemia*. The scatter plot for those two variables shows that there is no clear linear pattern for the distribution of *Artemia* cysts in the near -bottom samples (Fig.35**A, D**).

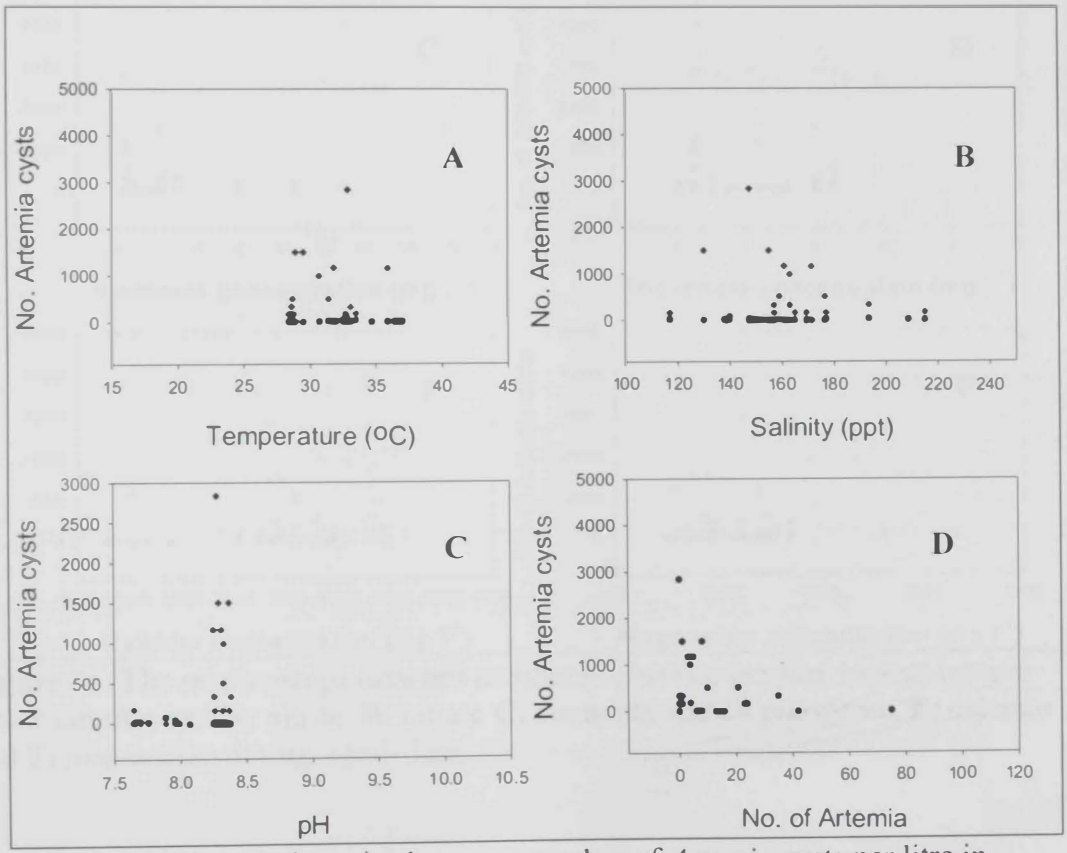

Figure 35. The relationships between number of *Artemia* cysts per litre in near-bottom water samples and **A:** temperature, **B:** salinity, **C:** pH and **D:** *Artemia* cysts number during April-June.

B. Effect of chemical factors

There was no significant correlation between number of *Artemia* cysts in near bottom samples during April-June versus nitrite, nitrate, ammonia, phosphate, calcium and magnesium concentrations (Table 29). The scatter plot for all these

variables (Fig.36A, B, C, D, E, F) shows that there is no strong linear pattern for the distribution of *Artemia* cysts in near bottom samples during the specified months.

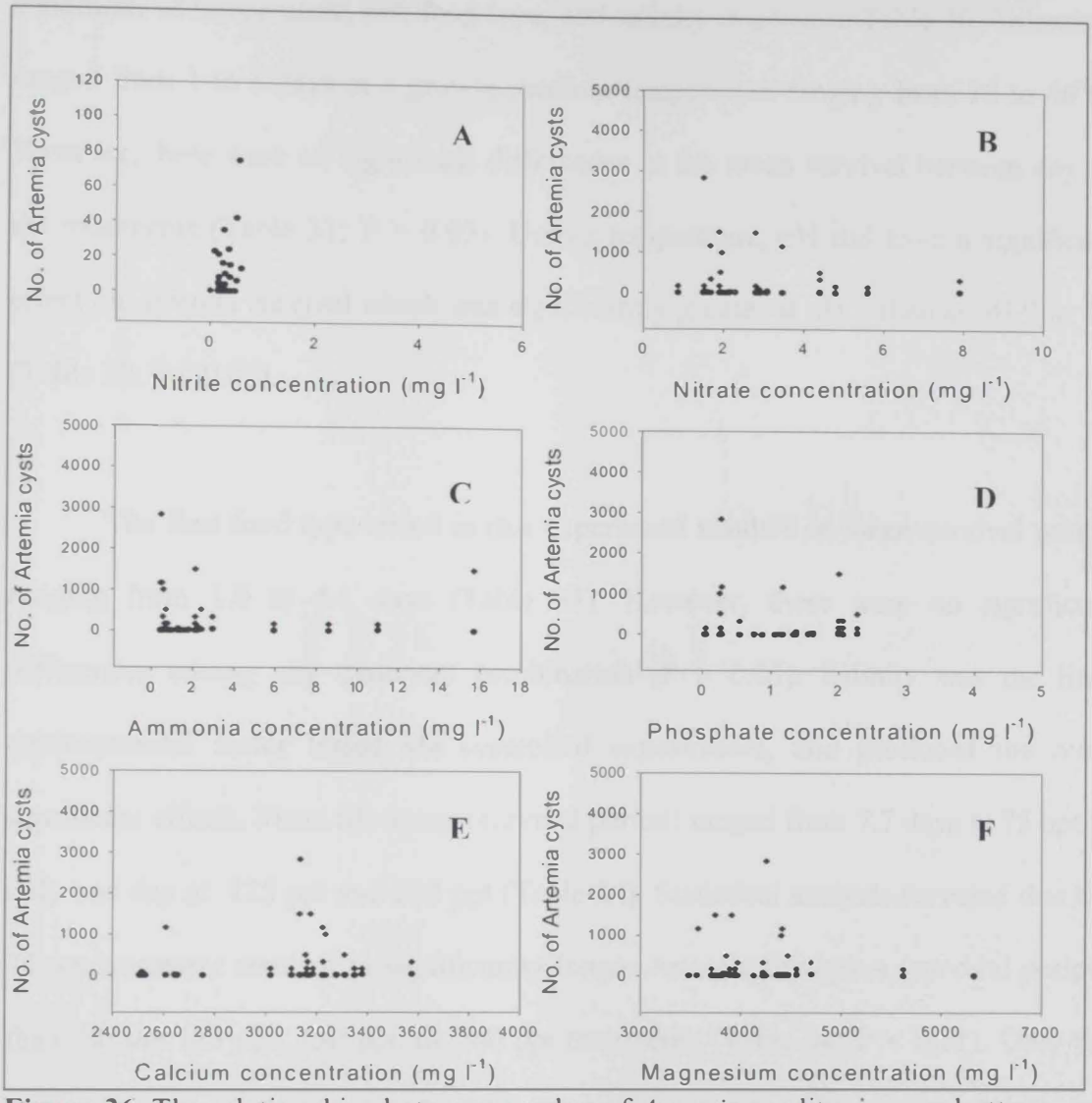

Figure 36. The relationships between number of *Artemia* per litre in near-bottom water samples and **A:** nitrite, **B:** nitrate **C:** ammonia and **D:** phosphate, **E:** calcium and **F:** magnesium during April- June.

12. *Artemia* tolerance experiment

The mean tolerance of *Artemia sp.* grown under a range of environmental conditions of temperature, pH, food type, and salinity is given in Table 30. Tolerance ranged from 1 to 6 days at a growth medium temperature ranging from 15 to 40°C. However, there were no significant differences in the mean survival between any of the treatments (Table 31; $P > 0.05$). Unlike temperature, pH did have a significant effect on *Artemia* survival which was significantly greater at pH 8 than at pH 9 or 10 (Table 32; $P < 0.05$).

The four food type tested in this experiment resulted in mean survival period ranging from 1.0 to 4.1 days (Table 33). However, there were no significant differences among any treatment combination ($P > 0.05$). Salinity was the final environmental factor tested via controlled experiments, and produced the most significant effects. Mean life spans (survival period) ranged from 7.7 days at 75 ppt to only one day at 125 ppt and 200 ppt (Table 34). Statistical analysis revealed that the 75 ppt treatment resulted in significantly longer Artemia life-spans (survival period) than did the 125 ppt, 150 ppt, or 200 ppt treatments (Table 34; $P < 0.01$). Only the 100 ppt treatment did not significantly reduce *Artemia* life spans compared to the 75 ppt treatment, although it did result in marginally longer life-spans compared to the 125 ppt, 150 ppt, and 200 ppt treatments ($P < 0.1$).

The statistical analysis indicated that the main factors significantly influencing the life span of *Artemia* were pH and salinity, while the other factors (food type and temperature) had no significant effect. The optimum pH and salinity for optimum life of *Artemia* organism in the present study were 8 and 75ppt, respectively.

Discussion

Discussion

Most of wetlands are very valuable ecosystems; however, some experiences showed that the value of wetlands can be reduced considerably when they are managed without adequate knowledge. Globally, wetland losses are monitored by Ramsar Convention, an international organization established in a 1971 meeting in Ramsar, Iran. The Convention aims at raising the international awareness of the importance and the ecological services provided by wetlands. It has also compiled a list of 1060 wetlands of international importance. Although few countries have the funds available for adequate protection or restoration, this list provides support-in the form of international recognition-for local activities working to control wetland losses (Cunningham *et al.*, 2003).

Al Wathba reserve is an artificial wetland developed as a result of the 1982 discharge of over-capacity treated sewage water from the Mafraq Waste Water Treatment Plant into low land. However, the standing water in the developed lake and its maintenance as a permanent lake, due to the continuous discharge from the adjacent plant, has attracted many animals and birds as a seasonal or permanent refuge, forming a valuable wetland environment that must be protected. The continuous inputs of water, some of which is saline/brackish and the high evaporation rates have lead to considerable changes in water salinity, with a range from freshwater to hyper-saline water (from 11 ppt to 250 ppt). The reserve is also known for its unique mosaic habitat which includes fresh lakes, saline lakes, sand dunes, marsh reeds and sabkha. This mosaic habitat is

actually considered a home for many birds as well as a main stop for other migrating birds, especially the greater flamingos.

In 1998 the lake and its surroundings were designated an protected area, known as "Al Wathba Wetland Reserve", and placed under the management of the Environmental Research and Wildlife Development Agency (ERWDA). This positive action toward an artificially developed wetland is arising from the great attention and interest of the UAE government in protecting and conserving natural resources and wildlife environment, either existing or developed within the UAE territory.

In fact, after the colonization of the flamingos and their breeding incidence in 1999, the site more importance, as this breeding is known to be the first breeding in the Arabian Peninsula from over than 75 years (Aspinall *et. al.,* 1999). Al Wathba Wetland Reserve is also considered a unique habitat that has not been found any where else in the country. Nonetheless, it represents a good example of co-existence in harmony between industry and nature. Without the water discharge from the Sewage Treatment Plant, Al Wathba Wetland would have not been existed. The prime role of Al Wathba Wetland Reserve is to provide breeding habitat for the greater flamingo as well as to support and conserve biodiversity in all its forms. It will also become an environmental education and research station for the Emirate of Abu Dhabi.

It has been reported that that brine shrimp is the main food source for the greater flamingos (Rooth, 1976, Cooper *et. al.*, 1984). It was also found that brine shrimp is the

only aquatic crustacean that inhabits Al Wathba Lake. Therefore, it was essential to study the lake ecology and the brine shrimp population dynamics and reproductive cycle, and their correlations with prevailing environmental conditions, with the aim to maintain their sustainability, and in turn, to guarantee the existence of the established flamingos population the whole year around. Before this study, very little information was available on brine shrimp that inhibit the lake. Therefore, the present study is the first detailed study to be carried out on *Artemia* sp. in the lake and in the whole Gulf region. Such a study was essential as a managerial tool, to provide the managers of the reserve with the necessary information about the brine shrimp population in Al Wathba Lake and its optimal growth conditions. This information is necessary for the maintenance and sustainability of the greater flamingos' population in the reserve.

The present study revealed that the climate of Al Wathba Wetland Reserve is similar to the climatic conditions of Abu Dhabi city, and reflects the climatic nature of the Gulf region, which is hot and humid during summer with a maximum air temperature of 48°C. In winter months (December-January), a minimum air temperature may reach 8 °C. Such great variation in seasonal temperature is seriously affecting not only the physical and chemical parameters of the water body of Al Wathba Lake, but also the living organisms (Kinne, 1963). On the other hand, and in addition to the seasonal variations in weather conditions the quantity and quality of water inputs from the adjacent waste water treatment plant significantly affect the stability of the lake ecosystem.

During the study period, summer air temperature was often high, resulting in high water loss through surface evaporation. The surface water temperature ranged from 36°C in summer to 18°C in winter with 2°C increase for the near bottom temperature (Fig.4). The high rate of surface evaporation during the summer months resulted in lowering water levels and increasing water salinity, which ranged from 263 ppt in summer to 11.5 ppt in winter (Fig.7). The pH values fluctuated between 7.6 and 10.0 during the study period. In an annual survey of the salt ponds of northeastern Brazil, Camara (2001) reported that water temperature ranges from 26.1 to 31.5°C, pH from 7.26 to 8.23, and salinity from 101 ppt to 177 ppt. These values, even they are not similar of what was found at Al Wathba Lake, they reflect certain conditions in similar latitudes. The differences may result from the nature of the water source as well as the nature of the bed-rock formation. It is well known that the Sabkha environment of Abu-Dhabi is very rich in carbonate materials.

Al Wathba Lake is different in its environment to many existing Lakes however, it is considered to be very small and shallow compared the lakes around the world. The Great Salt Lake is the largest saline lake in the Western Hemisphere located in USA with NaCl (85%) dominant salt in the lake (Wurtsbaugh *et. al.*, 2001). They reported that the salinities in this closed basin lake vary with the climatic cycles which ranged from 50 to 250 ppt over the past 30 years and with average depth of 4.9 m. In addition, the physical characteristics of Al Wathba Lake are similar to the Mono Lake in USA but in a smaller scale. The Mono Lake is an alkaline hyper-saline lake located east of Sierra Nevada in USA and covers 160 km^2 with a mean depth of 18 m (Jellison *et .al.*, 2001). Not

surprisingly, they stated that chloride; carbonate and sulphate are the dominant anions with salinity more than 85 ppt and pH 10 which is similar to what we found in Al Wathba Lake. Moreover, we found that the *Artemia* is the main aquatic invertebrate that inhabits Al Wathba Lake which is smiliar to the Mono Lake as well. Lenz & Cooper (1986) stated that the Mono Lake has a simple food web, with brine shrimp *Artemia monica* as the major grazer. Nonetheless, Lake Urimah in Iran is a large thalassohaline hyper-saline lake with salinity range from 150-180 ppt and average depth of 16 m (Van Stappen *et. al.*, 2001). They found that the surface temperature ranged between 3.1°C (December) and 27.5°C (August) during survey in 1995. while, a survey during 1989-1990 in Lake Torrens in Australia (maximum length of 220 km and width of 70 km) recorded salinity range between 16 ppt to 249.5 ppt with maximum air temperature of 40°C in summer and 1°C in winter (William *et. al.*, 1998).

Since there is no means of reducing water levels at the lake (through outflows), fluctuations in the water level are due to a combination of the rate of water input (either through direct input or ground water level) and the rate of loss through surface evaporation. The rate of water input from the adjacent treatment plant was increased in summer to compensate the water loss from the lake through the evaporation and to maintain a constant water level. The effects of ground water were not known, as there are no bore holes, either on site or nearby, for measuring ground water levels. During winter, there was little water input from rainfall during the survey period. Therefore, inputs from the Sewage Treatment Plant were the only source of fresh water for the lake. The studied chemical factors studied were affected by the water dynamics described above.

Fluctuations of low and high water levels caused an increase and decrease in the concentrations of phosphate, ammonia, nitrate, nitrite, calcium and magnesium (Figures.9, 10, 11, 12, 13, and 14). Such fluctuation did not show significant effect on the phytoplankton diversity in the lake. In fact, the only existing algae species in the lake is the *Dunaliella* sp., which representing the food source for the *Artemia* population. The fluctuations of the *Dunaliella* population density during the study period was in fact related to the seasonal variation in temperature more than to the nutrients concentrations. Where, the high temperature and the consequent increase in water salinity during the summer, could be the main factors controlling the increase in *Dunaliella* population, in addition to the variation in grazing intensity by *Artemia* organisms . It has been reported that, in inland water bodies, the continuous fluctuations in their water level and the increase of their water salinities may negatively alter the abundance and the survival of their biota (Williams, 2001). Another factor that could have affected the lake environment and its heterogeneity is the physical structure of the lake. The lake is composed of several connected water bodies rather than a single large body. When water levels drop down in summer these water bodies tend to become disconnected. Due to the low rate of water mixing, each of these separate water bodies, even when connected has unique properties and therefore provides unique environmental conditions.

The seasonal fluctuations in water levels, water salinity and water temperature have revealed an extreme effect on the *Artemia* population of Al Wathba Lake. In summer, when the temperature was high, the *Artemia* population dropped down and the number of the cysts increased. Statistical analysis revealed that this decrease in *Artemia*

population was attributed to the high temperature and salinity. Correlation analysis of the data (physical and chemical) revealed that there was no significant correlation between *Artemia* and cysts numbers with any of the variables (nitrite, nitrate, ammonia, phosphate, calcium and magnesium) except for the pH, water temperature and water salinity. Wear & Haslet (1986) reported that temperature and salinity rarely acted independently. Moreover, Browne *et. al.* (2000) mentioned that there is often a complex relationship between the two factors where the temperature can modify the effects of salinity, and therefore changing the salinity tolerance range of the *Artemia.* In addition, laboratory results of Wutsbaugh *et al.* (2001) showed that *Artemia* growth and cyst production over 12 months were highly dependent on temperature and slightly on food level. They reported that under 25°C and high food levels, *Artemia* grew rapidly and reached lengths of 9 mm in 12 days after the hatching of the cyst. Similarly, Browne *et. al.* (2000) indicated that at 30°C *Artemia* approaches their upper temperature limit for successful reproduction. In the mean time, on-site observations of Tackaert & Sorgeloos (1991) indicated that the *A. parthenogenetica* population from Tanggu Lake in China experienced high mortality at high salinities, but *A. franciscana* appears more euryhaline, exhibiting high survival and better reproductive characteristics in a boarder range of salinities (Wear *et. al.*, 1986).

In a very recent study of the salinity effect on four Egyptian *Artemia* populations, Baxevanis *et al.*, (2004) found that the parthenogenetic populations were more euryhaline compared to the bisexual one. Moreover, the bisexual population showed significantly lower reproductive output compared to the parthenogenetic ones and performed best at a

salinity of 35 g l^{-1}. These finding could also explain more the absence of *Artemia* organisms from Al Wathba Lake during the summer months. Where, due to the high temperature of the lake water and the consequent increase of water salinity (237.5 ppt in June) *Artemia* population started to die and cysts numbers were high in that period of sampling.

On the other hand, Wear & Haslett (1986) reported that more than 90% of the *Artemia* nauplii survived to maturity within a temperature range of 20-28°C and a salinity of 120-200 ppt. Moreover, Basil *et. al.* (1987) reported that the occurrence of *A. parthenogenetica* in India at temperatures ranging from 34 to 36°C and salinities of 155-204 ppt, however, it is not confirmed whether this occurrence represents a transitional or permanent population.

In winter, when water temperature was low (18.6°C) and salinity was favorable (70.4 ppt) for the growth of *Artemia* organisms, the cysts number decreased. This result is also close to what was found by Abatzopoulos *et. al.* (2003), who reported that the parthenogentic clone from Embolon salt works performed best at 80 ppt and at a temperature of 22°C. It was also confirmed that the incubation temperature significantly affects cysts hatchability in all *Artemia* strains and the hatching percentage is always maximal at 25°C up to 30°C and this pattern of absence or presence of *Artemia* population or cysts was repeated and significantly affected by the pH as well (Vanhaecke *et. al.*, 1989).

On the other hand, during the winter season, although the water temperature decreases (i.e.≈8°C), the salinity remains high. Such conditions favor the development of algal blooms, mainly related to the *Duanlliela* species. The increase in pH of the water could be a consequence of algae bloom photosynthesis and/or the high calcium ion concentrations which characterize the sabkha substrate of the lake. The fluctuation in water temperatures in the summer and winter seasons, coupled with the high pH and salinity values in the lake water throughout the year have certainly had an impact on the dynamics of the *Artemia* population. This is demonstrated by the absence of living *Artemia* organisms in samples collected during the summer months, but the presence of cysts in high numbers. Conversely, during the winter months the cyst numbers are low.

In the present study, the laboratory experiments on the survival of the *Artemia* organisms under the different tested conditions have shown that *Artemia* tolerance was affected mostly by pH and salinity ($P<0.05$). It was also proved that Al Wathba *Artemia* sp. cultured at 25°C, had longer life span and wider tolerance at lower salinity (75 ppt) with lower pH (pH 8). Another study carried out by Traintaphyllidis *et al.* (1995) indicated that the optimum salinity for a parthenogenetic species from China is between 60 ppt and 100 ppt.

In the laboratory experiments, it has been also found that Al Wathba Lake *Artemia* survival and tolerance was greater at lower temperatures (between 25°C and 30°C) than higher temperature (40°C), but the difference was not significant. The laboratory findings about the effects of temperature were similar to what was found in the

field survey, regarding the absence and presence of *Artemia* and cysts. In that concern, Browne *et. al.* (1988) reported that *A. franciscana* stands out among the populations studied in its reproductive performance at extreme temperatures range from 27.5°C to 32.5°C.

Once again, it is necessary to mention that, the taxonomic identification of the *Artemia* sp. that inhabit Al Wathba Lake has been carried out with the co-operation of the *Artemia* Reference Centre at Ghent University, Belgium. From the initial identification, the Centre suspected that this species belongs to *A. franciscana.* However, such preliminary identification may not be sufficient to confirm the species-specific identity of Al Wathba Artemia population. That is mainly because of the striking information available in literature regarding the lifespan, the survival and the tolerance of *A. franciscana*, which some times becoming more related to local environmental features than the genetic ones. In their study Baxevanis *et al.,* (2004) have recorded for the first time the inhabiting *of A. salina* in an Egyptian carbonate lake. They concluded that, such findings may provide valuable information on *Artemia* biodiversity.

In this study, the *Artemia* population inhabiting Al Wathba Lake was found to be significantly affected by water temperature and salinity. This result is in agreement with the results of several researchers (Browne *et.al.*, 1984; Wear *et.al.*, 1986; Browne, 1988; Vanhaecke, 1989; Triantaphyllidis *et.al.*, 1995; Herbest, 2001; Camara, 2001; Van Stappen, 2001; Browne *et al.*, 2002).

Other studied variables including the chemical characteristics of the water body had no significant effect on the presence or absence of the *Artemia* population or their cysts in the lake. Moreover, the *Artemia* tolerance experiment data indicated that salinity and pH had a significant effect while food type and temperature had no significant effect. Moreover, the carbonaceous nature of the surrounded sabkha, which also represent the lake basin, may have a side effect on the life cycle and reproduction of the existing *Artemia* species, unless it is genetically adapted.

In that concept, it is necessary to carry out further genomic taxonomic investigation on the *Artemia* sp. of Al Wathba Lake to confirm the primary identification and whether it belongs to *A. franciscana* or *A. parthenogenetic.*

Despite that *Artemia* sp. inhibiting Al Wathba Lake are significantly by and sensitive to temperature and salinity, water temperature can not be controlled, while salinity can be managed to favor *Artemia* performance in the lake by controlling the fresh water inputs, especially in summer. It is strictly recommended to stop fresh water input during the summer and start it again in winter (October) when temperature starts to decrease. Stopping fresh water input in summer will likely allow the water level to drop down to its maximum due to evaporation. Therefore, when the water starts to cool down in winter, a huge amount of fresh water can be pumped into the lake. By following this scheme, cysts will start to hatch and *Artemia* life cycle will continue. This process will provide a sustainable food source for flamingo until end of winter (April).

Here, it is important to note that, although the ecosystem of Al Wathba Lake is considered as a small relatively simple one, the behaviour of the different components in the system and their interaction was a necessary first step in the design of a successful management plan. Therefore, and in order to make the lake ecosystem perform as successful as desired, a comprehensive guideline was written as an output from this study for managing the water body of Al Wathba Reserve. The purpose of this guideline is to help the managing authority to understand the ecology of the *Artemia* sp. of Al Wathba Lake and to make the proper management decisions for the water body in favor of blooming and sustainability of the *Artemia* population.

The following Guidelines are written as a summarized report describing the lake environment and the problem faced its ecosystem. The report extends until reaching the main steps to be followed in order to have a sound management. In fact, this report has submitted to the ERWDA decision makers and they are actually applying it with success.

GUIDELINES FOR THE MANAGEMENT OF THE BRINE SHRIMP POPULATION AT AL WATHBA LAKE

Introduction

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 with a maximum depth of almost two metres. Al Wathba Lake exists primarily because it is supplied with secondary 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 because of the underlying sabkha substrate. The maximum salinity recorded in the lake is 250 ppt which is approximately 4.5 times higher than that of sea water.

The sabkha substrate and high evaporation rates have made the water body a hyper-saline habitat. The only invertebrates that are able to live in this harsh habitat are brine shrimps (*Artemia* sp.) and occasionally blood worms (*Chironomus* sp.), that both feed on algae. Brine shrimps, in turn, are the main food source for the greater flamingos (*Phoenicopterus ruber*). They also provide supplementary food for other wading bird species that feed mainly on algae.

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 first stage larva which is known as a nauplius larva. The larvae remain in this stage for about 12 hours 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 12^{th} moult they are termed post-larval and by the 17^{th} moult they are regarded as adult From the second instar onwards, they feed on small algal cells; by the time they reach an adult size of 10mm 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 under such optimum conditions.

Brine shrimp inhabit hyper-saline lakes and ponds where there are few aquatic predators and competitors. The salt content of these lakes may reach 250 ppt compared to a salinity of about 35 ppt in sea water. In general, brine shrimp can survive temperatures between 6° C and 40° C with an optimum range of 25° C to 30° C; whilst cysts can tolerate a much wider range of temperatures from below freezing to almost 100° C. Salinity thresholds can vary for different starins of *Artemia*. In general, the *Artemia*

species inhabiting Al Wathba Reserve can tolerate salinities up to 200 ppt and a pH range from 7 to 10, whilst the optimal pH range for cyst hatching is 8 to 8.5.

The *Artemia* study was conducted in order to understand the relationship between the environmental conditions and brine shrimp population dynamics. The study started in early 2002 and has continued for more than a year. Water samples were collected monthly from 14 fixed sites at the surface and bottom of the water column. The parameters measured were water temperature, depth, salinity, pH, nitrite, nitrate, phosphate, Ca^{++} and Mg^{++}. *Artemia* adults and cysts present in the samples were counted in the laboratory under a stereomicroscope.

Purpose of the guidelines

The purpose of the guidelines is to allow decision makers to develop a management regime for the water level of the lake. Appropriate management of the water level has an influence on the salinity of the lake which has a direct effect on the population of *Artemia* which in turn influences the numbers of Flamingos resident and potentially breeding at the lake.

Parameters that should be controlled

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.

The need for year-round water level management

Water level in summer is one of the key factors ensuring maximum breeding of *Artemia*. If the water level is low, temperature and salinity will increase and cysts will be formed. Following this, at the beginning of winter when the ambient temperature has fallen, fresh water can be input to 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. If, on the other hand, the water level remains high in summer, the *Artemia* population will simply die due to temperature increase and few cysts will be formed. Furthermore, because the levels are high, it will be impossible to input sufficient fresh water from the Mafraq Waste Water Treatment Plant to trigger cyst hatching, and consequently the population will not develop.

The relationship between *Artemia* and salinity

Salinity is one of the most important physical factors affecting the Artemia life cycle at the lake. As ambient temperature increases, the water salinity subsequently increases due to evaporation. Normally, at salinities of less than 80 ppt, *Artemia* reproduce by laying eggs, which hatch immediately upon contact with water (such a strategy is referred to as being ovoviviparous). As the salinity increases above 80 ppt the eggs no longer hatch on contact with water, but instead become cysts; they do this by forming a hard outer shell (known as a chorion) around the egg itself. Cysts will only hatch when the salinity is less than 25 ppt. Consequently, if at some point the salinity has exceeded 80 ppt, then in order to restore the *Artemia* population, it is necessary to try to

reduce the salinity to less than 25 ppt, or to at least have some parts of the lake where the salinity is less than 25 ppt.

Relationships between *Artemia* and temperature

Temperature is the other major factor that has direct effect on the population dynamics of Artemia. *Artemia* are able to survive relatively high temperatures, up to 40° C. However, they stop reproducing as temperatures rise above 30° C. Consequently, we have to accept that as summer approaches natural mortality within the Artemia population will increase (the summer water temperature at Al Wathba regularly exceeds 40° C at 1.75m depth). During winter, when the water body falls to approximately 20 ° C, reproductive rate will increase, provided that salinity is less than 80 ppt and that the Artemia are reproducing using the ovoviviparous strategy.

Potential risks

1. Failure to reduce the water level during summer

Failure to reduce water level during summer has an effect on water input in winter. In winter, when the temperature falls to within the optimum range required for cyst hatching, it would be impossible to put sufficient amount of fresh water into the lake in order to decrease the salinity (see: The need for all year-round water level management). It is strictly recommended to avoid any excessive water inputs to the lake during summer thus allowing it to partly dry out (by evaporation as a result of temperature increasing up to 48° C). Drying the lake in summer will help towards putting sufficient amounts of fresh water in winter to enhance the hatching process. Also, it will

help to combat the algal blooms that have occurred towards the end of summer, in the past.

2. Insufficient fresh water input during early winter

Insufficient fresh water input during early winter (the beginning of the hatching and breeding season of *Artemia*) will also have an effect. Too little water input to the lake would fail to reduce the salinity and cysts will remain dormant. If the reason for too little fresh water being input is that the water levels are too high, then we recommend using pumps to lower the water level in order that fresh water can be input. Without low salinity water input, the *Artemia* population will simply not develop.

3. Salinity greater than 80 ppt throughout the lake during winter

If the salinity is greater than 80 ppt throughout the lake during winter either because of insufficient low salinity water input or because of failure to reduce water levels in summer, the cysts will not hatch and thus remain dormant. It is not necessary to reduce the salinity in the whole lake but it is important to have some parts of the lake with lower salinities (below 25 ppt) where cyst may be able to hydrate and complete their life cycle.

4. Effect of Algal blooms

Algae are known to be the main food source for *Artemia*. The algal growth will start to increase if cyst did not hatch in winter due to any above mentioned reasons. This situation where the main predator of algae is absent would drive algae to bloom in the

lake which also known as red tide. Following the bloom, algae death and subsequent decomposition can deplete dissolved oxygen in water thus making the habitat unsuitable for organisms requiring dissolved oxygen such as brine shrimp. To avoid such situation the lake should be dried in summer so the over growth of algae will start to die because of dehydration.

Glossary

Artemia: is a small crustacean belongs to the phylum *Arthropoda* (joint-legged invertebrates).

Cysts: fertilized eggs that surrounded by a thick shell which are in diapauses.

Fresh water: secondary treated waste water.

Algae bloom: it is an increase in the number of algal cells especially in summer.

Ovoviviparous: fertilized eggs that are developed into free-swimming nauplii by the female shrimp.

Blood worm: is a red colour larva of mosquito.

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Appendix

Table.1. Air temperatures (°C) recorder during the study form April 2002 to January 2003.

Dry Temperature (°c)							
Day	**Min**	**Max.**	**Avg.**	**Day**	**Min.**	**Max.**	**Avg.**
01-Apr-02	20.29	38.06	28.75	01-May-02	20.53	43.95	32.23
02-Apr-02	21.56	41.17	32.56	02-May-02	22.35	44.99	34.12
03-Apr-02	22.85	42.07	31.65	03-May-02	24.62	45.05	35.81
04-Apr-02	17.85	27.19	22.73	04-May-02	24.36	43.94	33.69
05-Apr-02	16.2	26.65	22.31	05-May-02	21.72	37.89	30.08
06-Apr-02	16.82	27.43	22.36	06-May-02	21.24	38.01	30.04
07-Apr-02	16.47	30.61	23.23	07-May-02	21.69	41.84	32.03
08-Apr-02	14.97	33.83	24.36	08-May-02	23.16	44.07	34.15
09-Apr-02	18.88	36.74	27.75	09-May-02	26.3	44.86	35.81
10-Apr-02	22.22	35.66	29.83	10-May-02	27.51	41.6	34.26
11-Apr-02	22.82	34.63	28.03	11-May-02	27.07	39.51	31.85
12-Apr-02	21.08	33.51	27.37	12-May-02	26.48	35.16	30.86
13-Apr-02	19.59	28.73	23.78	13-May-02	25.74	39.01	32.61
14-Apr-02	18.1	31.43	24.48	14-May-02	22.2	36.69	29.89
15-Apr-02	17.84	31.71	24.82	15-May-02	20.87	37.32	28.6
16-Apr-02	18.16	30.86	24.49	16-May-02	20.18	41.57	30.99
17-Apr-02	18.16	36.01	26.03	17-May-02	23.31	41.31	32.46
18-Apr-02	20.58	38.11	29.08	18-May-02	23.64	43.38	32.87
19-Apr-02	21.99	39.95	31.48	19-May-02	24.12	45.22	33.99
20-Apr-02	25.37	41.5	34.18	20-May-02	23.38	45.83	34.08
21-Apr-02	24.32	34.82	28.65	21-May-02	25.79	47.14	35.65
22-Apr-02	23.07	36.94	27.93	22-May-02	24.3	41.05	32.8
23-Apr-02	19.53	31.9	25.6	23-May-02	24.24	43.71	33.08
24-Apr-02	18.18	30.27	24.5	24-May-02	23.7	43.29	33.56
25-Apr-02	17.69	36.3	26.23	25-May-02	24.15	44.32	33.46
26-Apr-02	19.37	40.93	29.01	26-May-02	24.76	46	34.02
27-Apr-02	21.49	41.07	29.28	27-May-02	25.24	44.37	33.65
28-Apr-02	21.68	42.38	31.35	28-May-02	25.08	40.39	32.72
29-Apr-02	21.15	43.35	32.26	29-May-02	23.66	45.08	34.35
30-Apr-02	21.58	42.81	32.12	30-May-02	26.15	45.52	34.95
				31-May-02	24.95	44.27	33.37

Cont.

Dry Temperature (°c)							
Day	Min	Max	Avg	Day	Min	Max	Avg
01-Jun-02	23.82	42.94	33.1	01-Jul-02	27.56	43.62	34.93
02-Jun-02	23.34	44	32.9	02-Jul-02	25.5	41.99	33.66
03-Jun-02	24.65	43.38	34.54	03-Jul-02	27.4	44.09	35.12
04-Jun-02	25.22	43.85	34.86	04-Jul-02	27.19	46.29	37.23
05-Jun-02	25.67	44.47	35.25	05-Jul-02	29.28	47.67	38.04
06-Jun-02	23.76	42.51	33.52	06-Jul-02	28.29	46.11	36.18
07-Jun-02	26.07	44.27	34.55	07-Jul-02	28.1	44.26	35.43
08-Jun-02	24.92	36.33	30.92	08-Jul-02	26.46	41.87	34.11
09-Jun-02	23.27	40.45	32.58	09-Jul-02	26.92	45.02	35.07
10-Jun-02	25.66	42.14	34.24	10-Jul-02	26.9	46.68	36.37
11-Jun-02	29.37	44.12	34.78	11-Jul-02	28.78	45.37	35.66
12-Jun-02	28.09	43.52	34.68	12-Jul-02	27.85	45.54	35.74
13-Jun-02	25.88	44.84	34.51	13-Jul-02	27.16	45.37	36.34
14-Jun-02	24.77	43.64	33.49	14-Jul-02	26.9	46.57	37.61
15-Jun-02	24.95	46.01	34.87	15-Jul-02	27.37	48.05	36.93
16-Jun-02	25.32	43.12	33.6	16-Jul-02	26.47	45.94	35.86
17-Jun-02	24.92	45.6	34.83	17-Jul-02	28.49	43.59	35.41
18-Jun-02	26.08	45.23	35.31	18-Jul-02	28.62	47.3	36.33
19-Jun-02	26.15	44.94	35	19-Jul-02	27.1	47.36	37.25
20-Jun-02	25.15	43.52	34.43	20-Jul-02	29.27	46.13	35.64
21-Jun-02	26.53	44.14	34.47	21-Jul-02	27.77	44.53	35.76
22-Jun-02	26.51	40.16	33.18	22-Jul-02	27.7	44.19	34.87
23-Jun-02	24.9	39.7	32.67	23-Jul-02	27.13	47.21	37.14
24-Jun-02	24.01	39.93	32.68	24-Jul-02	29.44	45.46	37.24
25-Jun-02	26.84	42.83	34.58	25-Jul-02	30.75	43.97	37.77
26-Jun-02	27.26	44.54	35.84	26-Jul-02	29.65	46.23	37.11
27-Jun-02	29.2	46.95	38.33	27-Jul-02	28.64	43.01	35.25
28-Jun-02	31.18	47.56	39.38	28-Jul-02	27.87	39.92	33.67
29-Jun-02	31.56	47.68	39.15	29-Jul-02	27.57	43.18	34.51
30-Jun-02	29.48	46.21	38.23	30-Jul-02	28.4	45.76	37.18
				31-Jul-02	28.65	46.67	37.55

Cont.

Dry Temperature (°c)							
Day	Min	Max	Avg	Day	Min	Max	Avg
01-Jun-02	23.82	42.94	33.1	01-Jul-02	27.56	43.62	34.93
02-Jun-02	23.34	44	32.9	02-Jul-02	25.5	41.99	33.66
03-Jun-02	24.65	43.38	34.54	03-Jul-02	27.4	44.09	35.12
04-Jun-02	25.22	43.85	34.86	04-Jul-02	27.19	46.29	37.23
05-Jun-02	25.67	44.47	35.25	05-Jul-02	29.28	47.67	38.04
06-Jun-02	23.76	42.51	33.52	06-Jul-02	28.29	46.11	36.18
07-Jun-02	26.07	44.27	34.55	07-Jul-02	28.1	44.26	35.43
08-Jun-02	24.92	36.33	30.92	08-Jul-02	26.46	41.87	34.11
09-Jun-02	23.27	40.45	32.58	09-Jul-02	26.92	45.02	35.07
10-Jun-02	25.66	42.14	34.24	10-Jul-02	26.9	46.68	36.37
11-Jun-02	29.37	44.12	34.78	11-Jul-02	28.78	45.37	35.66
12-Jun-02	28.09	43.52	34.68	12-Jul-02	27.85	45.54	35.74
13-Jun-02	25.88	44.84	34.51	13-Jul-02	27.16	45.37	36.34
14-Jun-02	24.77	43.64	33.49	14-Jul-02	26.9	46.57	37.61
15-Jun-02	24.95	46.01	34.87	15-Jul-02	27.37	48.05	36.93
16-Jun-02	25.32	43.12	33.6	16-Jul-02	26.47	45.94	35.86
17-Jun-02	24.92	45.6	34.83	17-Jul-02	28.49	43.59	35.41
18-Jun-02	26.08	45.23	35.31	18-Jul-02	28.62	47.3	36.33
19-Jun-02	26.15	44.94	35	19-Jul-02	27.1	47.36	37.25
20-Jun-02	25.15	43.52	34.43	20-Jul-02	29.27	46.13	35.64
21-Jun-02	26.53	44.14	34.47	21-Jul-02	27.77	44.53	35.76
22-Jun-02	26.51	40.16	33.18	22-Jul-02	27.7	44.19	34.87
23-Jun-02	24.9	39.7	32.67	23-Jul-02	27.13	47.21	37.14
24-Jun-02	24.01	39.93	32.68	24-Jul-02	29.44	45.46	37.24
25-Jun-02	26.84	42.83	34.58	25-Jul-02	30.75	43.97	37.77
26-Jun-02	27.26	44.54	35.84	26-Jul-02	29.65	46.23	37.11
27-Jun-02	29.2	46.95	38.33	27-Jul-02	28.64	43.01	35.25
28-Jun-02	31.18	47.56	39.38	28-Jul-02	27.87	39.92	33.67
29-Jun-02	31.56	47.68	39.15	29-Jul-02	27.57	43.18	34.51
30-Jun-02	29.48	46.21	38.23	30-Jul-02	28.4	45.76	37.18
				31-Jul-02	28.65	46.67	37.55

Cont.

Dry Temperature (°c)							
Day	Min	Max	Avg	Day	Min	Max	Avg
01-Aug-02	29.41	47.23	37.23	01-Sep-02	29.67	41.84	34.68
02-Aug-02	28.73	47.63	37.94	02-Sep-02	29.53	42.87	35.54
03-Aug-02	28.1	47.65	36.73	03-Sep-02	31.28	45.04	36.57
04-Aug-02	26.36	46.8	35.75	04-Sep-02	28.4	45.12	35.71
05-Aug-02	26.4	45.94	36	05-Sep-02	28.2	42.68	34.6
06-Aug-02	27.12	45.49	36.04	06-Sep-02	27.67	43.04	34.37
07-Aug-02	30.01	43.55	36.02	07-Sep-02	25.97	41.44	33.22
08-Aug-02	29	44.46	36.1	08-Sep-02	24.62	44.42	33.52
09-Aug-02	29.26	44.2	35.88	09-Sep-02	25.81	43.85	34.65
10-Aug-02	26.27	42.22	34.64	10-Sep-02	27.16	41.55	33.54
11-Aug-02	25.11	43.66	34.33	11-Sep-02	26.57	41.59	33.3
12-Aug-02	27.59	41.94	34.6	12-Sep-02	27.38	42.1	33.42
13-Aug-02	28.69	43.14	35.08	13-Sep-02	28.12	41.11	33.94
14-Aug-02	28.6	43.12	35.95	14-Sep-02	26.41	40.36	32.54
15-Aug-02	29.76	43.48	35.67	15-Sep-02	25.28	40.42	31.93
16-Aug-02	27.6	44.37	34.96	16-Sep-02	25.77	39.92	31.89
17-Aug-02	26.08	43.61	34.62	17-Sep-02	24.12	39.72	31.18
18-Aug-02	28.11	40.11	34.53	18-Sep-02	23.8	42	32.26
19-Aug-02	29.02	43.14	34.99	19-Sep-02	24.24	41.93	32.85
20-Aug-02	29.18	45.32	35.78	20-Sep-02	25.18	41.58	33.77
21-Aug-02	27.86	44.74	35.17	21-Sep-02	24.78	40.94	33.07
22-Aug-02	27.13	45.41	33.89	22-Sep-02	23.63	40.38	32.01
23-Aug-02	25.62	41.98	33.82	23-Sep-02	24.76	41.44	32.72
24-Aug-02	29.16	39.93	35.13	24-Sep-02	27.24	41.21	33.19
25-Aug-02	31.02	41.82	35.11	25-Sep-02	27.54	42.96	33.78
26-Aug-02	27.34	40.97	34.19	26-Sep-02	24.81	40.84	33.08
27-Aug-02	27.15	45.08	35.99	27-Sep-02	23.86	42.2	32.64
28-Aug-02	28.96	44.64	37.47	28-Sep-02	24.83	41.47	32.7
29-Aug-02	29.41	42.61	35.81	29-Sep-02	24.01	42.22	31.19
30-Aug-02	29.56	40.77	34	30-Sep-02	22.04	40.83	31.76
31-Aug-02	28.91	40.7	34.31				

Cont.

Dry Temperature (°c)							
Day	Min	Max	Avg	Day	Min	Max	Avg
01-Oct-02	25	39.84	33.04	01-Nov-02	20.31	34.37	27.25
02-Oct-02	24.8	39.44	31.58	02-Nov-02	20.11	34.8	27.28
03-Oct-02	23.31	38.73	31.15	03-Nov-02	21.26	34.08	27.11
04-Oct-02	23.41	37.88	30.29	04-Nov-02	21.07	33.03	26.95
05-Oct-02	23.76	37.19	30.55	05-Nov-02	20.83	32.69	26.79
06-Oct-02	22.82	39.58	30.6	06-Nov-02	19.41	33.66	26.65
07-Oct-02	23.12	42.4	31.28	07-Nov-02	20.49	32.78	25.59
08-Oct-02	21.72	39.08	30.33	08-Nov-02	19.89	30.51	24.82
09-Oct-02	25.11	41.05	31.98	09-Nov-02	18.42	32.21	25.62
10-Oct-02	22.54	40.42	31.59	10-Nov-02	18.7	31.94	25.37
11-Oct-02	23.84	37.41	30.43	11-Nov-02	19.08	31.52	24.88
12-Oct-02	23.18	40.7	31.58	12-Nov-02	17.82	32.11	25
13-Oct-02	23.61	38.34	29.98	13-Nov-02	18.65	33.01	25.28
14-Oct-02	21.99	39.63	29.89	14-Nov-02	18.56	33.75	25.92
15-Oct-02	21.08	40.5	30.62	15-Nov-02	18.85	30.89	24.87
16-Oct-02	20.57	39.75	29.68	16-Nov-02	19.63	29.96	24.2
17-Oct-02	21.54	39.94	30.16	17-Nov-02	18.28	29.15	23.07
18-Oct-02	20.47	39.73	29.83	18-Nov-02	16.38	30.74	23.46
19-Oct-02	20.3	38.69	29.23	19-Nov-02	17.94	30.89	24.29
20-Oct-02	19.66	37	28.35	20-Nov-02	17.9	30.67	23.99
21-Oct-02	19.41	37.11	27.92	21-Nov-02	17.77	27.94	22.43
22-Oct-02	19.46	38.41	28.8	22-Nov-02	16.28	28.4	22.12
23-Oct-02	20.19	37.17	28.29	23-Nov-02	15.04	29.52	22.15
24-Oct-02	20.51	37.8	29.96	24-Nov-02	15.74	29.51	22.92
25-Oct-02	22.12	35.33	28.68	25-Nov-02	16.65	28.82	22.16
26-Oct-02	20.97	33.53	27.92	26-Nov-02	14.58	28.61	20.93
27-Oct-02	20.03	34.4	27.38	27-Nov-02	15.76	27.43	21.1
28-Oct-02	22.3	35.79	29.42	28-Nov-02	15.02	26.9	20.29
29-Oct-02	21.36	35.25	28.16	29-Nov-02	13.82	26.77	20.41
30-Oct-02	21.7	36.05	28.74	30-Nov-02	12.97	27.84	20.08
31-Oct-02	21.39	35.77	28.06				

Cont.

Dry Temperature (°c)							
Day	Min	Max	Avg	Day	Min	Max	Avg
01-Dec-02	11.93	29.99	21.39	01-Jan-03	11.05	23.51	16.78
02-Dec-02	15.26	31.06	22.67	02-Jan-03	12.31	22.81	18.01
03-Dec-02	14.69	28.59	22	03-Jan-03	16.14	23.9	20.94
04-Dec-02	16.81	29.4	22.45	04-Jan-03	13.59	24.37	19.18
05-Dec-02	15.01	28.14	20.97	05-Jan-03	11.01	24.95	17.17
06-Dec-02	13.32	28	20.48	06-Jan-03	8.89	23.84	16.66
07-Dec-02	13.58	28.87	21.18	07-Jan-03	10.18	24.52	17.52
08-Dec-02	14.79	30.02	21.74	08-Jan-03	12.09	24.91	18.1
09-Dec-02	16.24	30.6	22.22	09-Jan-03	10.56	25.65	17.56
10-Dec-02	16.87	28.7	22.87	10-Jan-03	12.12	25.86	18.14
11-Dec-02	17.16	29.35	22.56	11-Jan-03	11.52	24.95	17.37
12-Dec-02	17.15	30.38	23.04	12-Jan-03	9.73	24.93	17.63
13-Dec-02	17.4	30.04	24.07	13-Jan-03	8.36	25.74	17.31
14-Dec-02	18.77	28.79	23.56	14-Jan-03	9.95	24.12	16.77
15-Dec-02	17.65	27.55	22.02	15-Jan-03	9.42	24.71	16.46
16-Dec-02	15.6	27.14	21.61	16-Jan-03	9.05	25.85	17.76
17-Dec-02	15.77	27.63	21.93	17-Jan-03	11.57	26.23	19.04
18-Dec-02	16.03	28.5	22.22	18-Jan-03	9.43	19.65	14.73
19-Dec-02	15.05	26.42	20.43	19-Jan-03	8.03	20.51	14.29
20-Dec-02	13.26	25.36	18.86	20-Jan-03	8.15	22.84	15.69
21-Dec-02	12.35	29.08	20.72	21-Jan-03	8.64	26.38	18.73
22-Dec-02	18.28	31.5	23.45	22-Jan-03	15.12	28.31	21.68
23-Dec-02	12.75	22.43	18.05	23-Jan-03	16.66	28.92	22.32
24-Dec-02	12.53	22.1	16.96	24-Jan-03	14.4	24.27	19.15
25-Dec-02	13.11	22.96	17.64	25-Jan-03	12.16	22.38	17.28
26-Dec-02	12.16	21.84	16.52	26-Jan-03	11.88	22.38	17.01
27-Dec-02	11.03	23.02	16.59	27-Jan-03	8.57	24.06	16.72
28-Dec-02	12.35	23.4	17.39	28-Jan-03	10.23	29.52	22.06
29-Dec-02	12.1	23.38	18.16	29-Jan-03	18.17	30.54	23.68
30-Dec-02	10.81	25.48	18.93	30-Jan-03	15.46	26.49	20.08
				31-Jan-03	11.89	24.05	18.21

Table 2. Depth measurements (m) for the whole 14 surveyed sites during the sampling period from April 2002 to January 2003

Month / Site #	April	May	June	July	August	September	October	November	December	January	Annual Average
W6644	0.75	0.70	1.00	1.25	0.75	0.75	0.75	1.20	1.20	1.20	0.96
W6545	1.00	0.80	1.50	1.75	1.00	1.00	1.10	1.20	1.40	1.20	1.20
W6446	1.00	0.80	1.00	0.75	1.00	0.75	1.20	1.20	1.30	1.30	1.03
W6246	1.25	1.20	1.25	1.50	1.25	1.20	1.50	1.50	1.60	1.50	1.38
W6146	1.30	1.75	1.25	1.25	1.50	1.25	1.60	1.70	1.80	1.70	1.51
W6074	1.50	0.25	0.20	0.20	0.20	0.25	0.50	0.35	0.25	0.30	0.40
W6050	0.10	0.20	0.15	0.20	0.20	0.20	0.60	0.50	0.25	0.35	0.28
W6049	0.20	1.50	1.50	1.75	1.60	1.50	1.60	1.90	2.00	2.00	1.56
W5950	1.00	0.75	0.75	0.75	0.75	1.00	1.10	1.20	1.00	1.20	0.95
W5851	0.10	0.20	0.20	0.25	0.20	0.20	0.30	0.25	0.25	0.50	0.25
W5850	0.20	0.20	0.15	0.30	0.25	0.15	0.20	0.20	0.20	0.20	0.21
W5749	1.20	1.10	0.50	0.75	1.25	1.00	1.50	1.50	0.60	0.30	0.97
Hyper2	0.20	0.30	0.25			0.25	0.30	0.20	0.25	0.20	0.24
Hyper1	0.80	1.00	0.75			0.40	0.50	0.50	0.40	0.65	0.63
Average	0.76	0.77	0.75	0.89	0.83	0.71	0.91	0.96	0.89	0.90	0.82

Table 3. Surface water temperature (°C) measured at the sampled stations during the study period from April 2002 to January 2003 with monthly and annual lake averages, and annual station averages.

Month / Site #	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Jan.	Annual Average
Hyper1S		32.6				30.5	26.7	23.2	19.4	22.7	25.68
Hyper2		32.6				30.3	27.3	23.4	19.1	23.4	25.76
W5749S	28.4	29.9	32.1	29	33.1	28.3	24.9	21.4	18.4	21.4	26.89
W5850	29.3	31.6	32.3	32.4	33.8	31.3	24.9	20.9	18.4	20.8	27.87
W5851	28.3	31.2	29.8	31.5	34.4	31.9	26	21	18.5	20.7	27.48
W5950S	29.1	32.8	33.4	31.4	35.9	30.5	25.8	21	18.6	20.9	28.18
W6049	29	32	32.8	29.4	33.1	28.5	25.4	20	18.4	21.6	27.20
W6050	29.5	38.3	33.2	34.8	38.1	31.8	24.8	20.8	18.2	21	29.52
W6074S	28.9	37.7	32.8	30.1	36.6	30.6	29.9	21	18.3	20.8	28.53
W6146S	28.8	32.4	32.8	28.6	34	27.9	25.5	19.5	18.8	21.9	27.19
W6246S	29	32.5	32.5	29.8	33.8	28.5	25.7	20.7	18.7	22.5	27.56
W6446S	28.9	31.4	31.8	28.5	34	28.4	25.7	20.9	18.5	21.7	27.12
W6545S	29.3	31.1	31.6	29.4	33.9	29	25.8	21.5	18.8	21.5	27.34
W6644	28.7	30.4	31.8	29.7	33.9	28.6	25.7	21.9	18.5	21.6	27.23
Average	28.93	32.60	32.24	30.38	34.55	29.72	26.00	21.22	18.61	21.60	27.77

Table 4. Near-bottom water temperatures (C^o) measured at the sampled stations during the study period from April 2002 to January 2003 with monthly and annual lake averages, and annual station averages.

Month / Site#	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Jan.	Annual Average
Hyper1D		32.7	37			30.2	26.7	23	19.3	22.3	27.31
W5749D	28.4	33.1	32	39.1	34.2	31.3	28.4	24.3	18.7	21.5	29.1
W5950D	28.6	35.9	34.7	41.5	36.2	32.5	33.2	23.9	20.6	21.9	30.9
W6047D	28.8	33.5	36.4	37.6	35.7	31.8	29.9	24.3	21.2	22.3	30.15
W6146D	28.6	32.9	36.6	40.1	35.1	30.7	31.3	23.8	20.4	22.1	30.16
W6246D	29.5	32.5	37	39.8	35.6	31.4	31.2	24.6	22.6	22	30.62
W6446D	28.6	31.8	32.5	0.36	35.4	29.8	30.1	23.1	19.7	22	25.33
W6545D	28.9	31.4	32.8	35	34.9	29.6	30.7	24.3	19.5	21.5	28.86
W6644	28.7	30.7	32.7	36.5	34.9	29	32	24.8	21	21.6	29.19
Average	28.7	32.7	34.6	33.7	35.2	30.7	30.3	24.0	20.3	21.9	29.24

Table 5. Surface water salinity (ppt) measured at the sampled stations during the study period from April 2002 to January 2003.

Month / Site #	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1S	165.5	223.5	237.5			184	59.2	175.2	66.8	85.2	162.53
Hyper2	162.5	186.5	204.5			154	73.2	168.4	71.2	84	147.30
W5749S	154	116.5	147	51.5	114.5	136.5	78.8	171.6	78	76.4	116.22
W5850	180	80.5	152	31.5	113.5	167.5	59.6	190.4	67.6	83.6	118.51
W5851	145.5	43	141.5	11.5	78	118.5	64.8	165.2	69.6	90.8	95.96
W5950S	147.5	125.5	162	70	128.5	178	78.8	188.8	72.8	78.4	127.94
W6049	144	150.5	159	144	114	135.5	75.6	194	69.6	84	132.73
W6050	157.5	167.5	154	114.5	133.5	142.5	60.2	200.4	68	86.4	136.03
W6074S	129.5	165.5	146	28.5	114	114	89.5	211.2	73.6	142.8	125.01
W6146S	156	157.5	158	162.5	139	137	73.2	152.8	66.4	81.2	134.49
W6246S	129	152	161.5	98.5	94.5	116.5	81.6	186	71.2	91.2	122.27
W6446S	165	169	141	116.5	95.5	154.5	66	185.6	70.8	82	131.10
W6545S	159	160.5	150.5	120	117.5	158	74.8	172.8	73.6	84.8	132.97
W6644	159	152	148	127.5	107.5	231.5	70.8	119.2	67.2	74.4	131.81
Average	153.8	146.4	161.6	89.7	112.5	152	71.8	177.2	70.4	87.5	127.93

Table 6. Near-bottom water salinity (ppt) measured at the sampled stations during the study period from April 2002 to January 2003.

Month / Site#	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1D	193.5	215	208.5			236.5	64.4	198.4	80	84	160375
W5749D	165	157	157	171.5	123.5	150	82.4	196.4	73.2	82.4	135.84
W5950D	117	161	150.5	152	117.5	137	55.2	197.6	91.2	97.2	127.62
W6047D	157	177	138	67	85	159	92.8	186.8	107.2	104.8	127.46
W6146D	163	147.5	152.5	163.5	101.5	130.5	80.4	200.4	92.4	91.2	132.29
W6246D	155	149.5	139	112	152.5	151	84.4	232.8	116.8	81.2	137.42
W6446D	169.5	171.5	147.5	157.5	125.5	138.5	94	178.4	88	102	137.24
W6545D	130	176.5	140	143.5	122	175.5	77.6	203.6	77.2	113.6	135.95
W6644	159	163	151.5	148.5	145.5	172.5	99.6	227.6	165.2	86.4	151.88
Average	156.5	168.6	153.8	139.4	121.6	161.1	81.2	202.4	99.02	93.6	137.75

Table 7. Surface water pH measured at sampled stations during the study period from April 2002 to January 2003.

Month / Site #	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1S		7.65	7.71			9.05	9.7	9.99	9.5	9.75	8.94
Hyper2		7.65	7.66			8.74	9.6	9.85	9.4	9.36	8.78
W5749S	8.37	8.29	8.07	8.16	9.04	9.21	9.9	10.4	9.9	9.58	8.96
W5850	8.44	8.23	7.81	8.08	9.27	9.46	9.79	10.5	9.9	9.42	8.96
W5851	8.37	8.29	7.8	7.76	9.29	9.4	9.75	9.98	9.8	9.27	8.88
W5950S	8.32	8.23	8.29	8.37	9.21	9.3	9.86	10.7	9.8	9.45	9.00
W6049	8.3	8.3	7.76	8.22	8.65	9.3	9.7	10.3	10	9.71	8.92
W6050	8.3	8.23	7.6	8.31	9.16	9.39	9.85	9.88	9.2	9.09	8.80
W6074S	8.37	8.24	7.76	8.31	9.18	9.46	9.53	10.5	9.8	9.24	8.93
W6146S	8.38	8.3	7.9	8.32	9.06	9.34	9.68	9.65	9.4	9.35	8.86
W6246S	8.37	8.3	7.99	8.22	8.91	9.31	9.54	9.93	9.5	9.33	8.87
W6446S	8.37	8.32	7.96	8.28	9.24	9.48	9.66	10	9.4	9.06	8.90
W6545S	8.37	8.33	7.89	8.27	9.26	9.42	9.59	10	9.3	9.47	8.92
W6644	8.33	8.34	7.76	8.08	9	9	8.94	9.86	9.2	9.06	8.74
Average	8.3	8.1	7.8	8.1	9.1	9.2	9.6	9.9	9.5	9.3	8.88

Table 8. Near-bottom pH measured at sampled stations during the study period from April 2002 to January 2003.

Month / Site#	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1D		7.65	7.66			9.15	9.81	10.1	9.8	9.79	9.13
W5749D	8.37	8.26	8.07	8.45	9.09	9.53	9	8.69	9.9	9.75	8.91
W5950D	8.32	8.25	8.29	8.22	9.21	9.42	8.9	9.03	8.8	8.82	8.72
W6047D	8.37	8.26	7.76	8.52	9.33	9.47	8.5	8.34	8.4	8.86	8.58
W6146D	8.38	8.28	7.7	8.48	9.21	9.52	8.29	8.46	8.2	8.91	8.54
W6246D	8.29	8.3	7.99	8.49	9.3	9.54	8.3	8.36	7.6	8.73	8.49
W6446D	8.37	8.31	7.96	8.44	9.29	9.57	9.28	8.66	8.4	8.34	8.66
W6545D	8.37	8.33	7.89	8.08	9.29	9.4	9.11	8.58	8.5	8.71	8.62
W6644	8.33	8.33	7.76	8.14	9.12	9.2	8.76	8.54	7.8	9.07	8.50
Average	8.35	8.21	7.89	8.35	9.23	9.42	8.88	8.75	8.6	8.99	8.67

Table 9. Surface phosphate concentration (mg l^{-1}) measured at the sampled stations from April 2002 to January 2003 with monthly and annual averages calculated for the whole stations respectively.

Month / Site #	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1S	1.79	06	1.13			0.31	0.6	0.32	0.47	0.56	0.66
Hyper2	2	06	1.24			0.38	0.67	0.51	0.49	0.51	0.74
W5749S	3.15	1.2	1.01	0.1	0.62	0.55	0.52	0.41	0.53	0.51	0.90
W5850	2.14	0.51	1.05	0.21	0.85	0.55	0.53	0.35	1.15	0.42	0.80
W5851	2.14	0.26	1.23	0.11	0.86	1.39	0.55	0.35	0.46	0.42	0.80
W5950S	1.93	0.38	1.06	0.21	0.55	0.62	0.53	0.32	0.46	0.49	0.67
W6049	2.2	0.37	0.97	0.19	0.4	0.53	0.51	0.8	0.58	0.49	0.73
W6050	2.61	2.06	1.13	0.91	0.33	0.48	0.55	0.34	0.41	0.47	0.97
W6074S	1.93	4.27	1.21	08	0.32	0.71	0.56	0.33	0.42	0.42	1.08
W6146S	1.79	0.31	1.11	0.21	0.39	0.53	0.49	0.88	0.52	0.46	0.69
W6246S	1.79	0.32	1.82	0.15	0.34	0.43	0.52	0.5	0.58	0.49	0.71
W6446S	1.86	03	1.75	0.28	0.26	0.41	0.51	0.63	0.56	2.66	0.94
W6545S	1.73	0.34	1.5	0.58	0.34	0.41	0.49	0.66	0.58	2.89	1.00
W6644	2.27	0.29	1.41	0.18	0.29	0.4	0.48	0.45	0.57	0.4	0.70
Average	2.09	0.74	1.25	0.26	0.46	0.55	0.53	0.48	0.55	0.79	0.80

Table 10. Near-bottom phosphate concentrations (mg l^{-1}) measured at the sampled stations from April 2002 to January 2003 with monthly and annual averages calculated for the whole stations respectively.

Month / Site#	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1D	2	05	1.15			0.39	0.59	0.34	0.48	0.52	0.69
W5749D	2	0.55	1.06	0.31	0.67	0.54	0.89	1.27	0.52	0.5	0.831
W5950D	2.27	1.17	0.87	0.25	0.38	0.46	0.66	0.83	0.45	1.38	0.872
W6047D	2.07	0.27	0.75	1.22	0.72	0.42	1.22	1.46	1.79	2.44	1.236
W6146D	2.07	0.27	1.55	0.39	0.47	0.42	1.24	1.42	1.36	1.4	1.059
W6246D	2	03	1.33	0.11	0.55	0.41	1.16	1.49	2.58	1.78	1.144
W6446D	2	0.28	1.62	0.19	0.35	0.39	0.66	1.48	1.09	0.39	0.845
W6545D	2	0.26	1.37	0.12	0.24	0.38	0.68	1.28	0.95	0.45	0.773
W6644	2.27	0.25	1.37	0.25	0.33	0.41	0.66	1.32	1.99	0.56	0.941
Average	2.07	0.34	1.23	0.35	0.46	0.42	0.86	1.21	1.24	1.04	0.926

Table 11. Surface ammonia concentration (mg l^{-1}) measured at the sampled stations from April 2002 to January 2003 with monthly and annual averages calculated for the whole stations respectively.

Month / Site #	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1S	4.45	0.92	0.71			0.51	0.33	0.11	09	0.23	1.00
Hyper2	11.9	1.39	0.63			0.2	0.47	0.16	0.1	0.26	2.09
W5749S	4.45	0.49	0.77	07	0.84	0.38	0.33	0.17	0.1	0.15	0.82
W5850	3.86	0.7	0.63	0.44	0.58	0.4	0.41	0.17	3.59	0.16	1.17
W5851	4.2	0.7	1.11	0.47	0.68	0.46	0.33	0.26	0.11	0.33	0.92
W5950S	2.73	0.62	1.02	0.21	0.63	0.43	0.34	0.14	0.1	0.22	0.68
W6049	8.01	0.51	0.9	0.38	0.65	0.36	0.23	0.18	08	0.21	1.25
W6050	3.5	0.64	1.59	0.77	0.65	0.34	0.3	0.12	09	0.21	0.88
W6074S	2.97	0.42	1.02	0.12	0.44	0.45	0.83	0.13	0.11	0.31	0.66
W6146S	2.29	0.46	0.88	0.67	1.92	0.35	0.33	0.17	09	0.23	0.78
W6246S	5.64	0.82	1.25	0.42	0.36	1.6	0.25	0.17	0.15	0.25	1.18
W6446S	3.26	0.51	1.46	0.22	0.43	0.31	0.3	0.19	0.15	9.78	1.81
W6545S	1.54	0.59	1.44	0.9	0.89	0.29	0.31	0.18	0.14	11.2	1.91
W6644	2.43	0.47	1.19	0.19	0.89	0.21	0.26	0.19	0.13	0.17	0.65
Average	4.37	0.66	1.04	0.40	0.74	0.44	0.35	0.16	0.35	1.69	1.10

Table 12. Near-bottom ammonia concentration (mg l^{-1}) measured at the sampled stations from April 2002 to January 2003 with monthly and annual averages calculated for the whole stations respectively.

Month / Site#	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1D	2.97	0.79	1.25			0.55	0.31	0.15	0.1	0.22	0.79
W5749D	5.94	0.56	0.86	2.8	2.25	2.32	3.17	5.23	0.1	0.16	2.33
W5950D	11	0.51	1.43	0.44	0.91	1.13	3.02	2.73	0.11	4.44	2.57
W6047D	2.13	0.64	0.94	3.5	4.55	1.56	4.89	5.48	7.64	9.78	4.11
W6146D	2.13	0.45	1.81	4.31	2.65	0.29	5.68	4.88	4.39	4.24	3.08
W6246D	2.13	0.51	0.99	0.56	4.2	1.81	4.43	5.95	11.5	6.08	3.81
W6446D	8.61	0.44	1.3	0.31	1.58	0.86	1.62	4.32	3.19	0.23	2.24
W6545D	15.7	0.68	2.25	0.92	0.82	0.35	2.12	4.86	2.26	0.15	3.01
W6644D	2.43	0.58	1.61	0.18	1.26	0.27	1.96	5.44	7.66	1.38	2.27
Average	5.89	0.57	1.38	1.62	2.27	1.01	3.02	4.33	4.10	2.96	2.71

Table 13. Surface nitrate concentration (mg l^{-1}) measured at the sampled stations from April 2002 to January 2003 with monthly and annual averages calculated for the whole stations respectively.

Month / Site #	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1S	4.3	0.86	2.84			1.5	2.4	1.72	1.3	0.37	1.84
Hyper2	2.7	0.76	2.81			1.63	1.94	1.68	1.39	0.36	1.62
W5749S	1.9	2.97	2.9	0.3	2.22	1.65	2.86	1.41	2.45	1.35	1.91
W5850	4.7	1.86	2.81	1.78	2.69	1.49	2.91	1.72	0.93	1.37	2.15
W5851	1.3	1.03	2.96	0.32	2.97	2.96	2.48	1.73	2.28	1.02	1.84
W5950S	2.9	1.51	2.8	1.58	2.16	1.73	3.05	1.45	2.1	1.48	1.97
W6049	4.2	1.88	3.06	3.88	2.35	1.77	2.62	1.45	2.59	1.41	2.51
W6050	3.3	4.67	2.87	1.08	2.07	1.26	2.49	1.85	1.91	1.01	2.22
W6074S	3.3	6.2	3.04	0.28	2.35	1.93	2.25	1.68	2.11	1.59	2.50
W6146S	5.8	1.53	2.02	1.48	1.75	1.77	3.31	1.56	1.82	1.34	2.12
W6246S	3.2	1.56	3.19	3.1	2.34	0.76	2.75	2.11	2.43	1.35	2.23
W6446S	2.8	1.86	3.2	2.37	2.3	1.52	2.91	2.24	2.52	0.29	2.12
W6545S	2.1	1.84	3.19	0.88	2.24	1.46	2.75	2.19	2.37	0.15	1.82
W6644	4.4	2.08	3.21	4.26	2.22	1.5	2.96	2.16	2.9	1.32	2.67
Average	3.35	2.18	2.92	1.77	2.30	1.63	2.69	1.78	2.07	1.02	2.12

Table 14. Near-bottom nitrate concentration (mg l^{-1}) measured at the sampled stations from April 2002 to January 2003 with monthly and annual averages calculated for the whole stations respectively.

Month / Site#	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1D	7.9	0.87	2.29			1.56	2.37	1.72	1.38	0.37	2.3075
W5749D	4.8	1.69	2.91	0.77	2.12	0.66	1.48	0.66	2.45	1.38	1.892
W5950D	5.6	3.46	2.06	3.6	2.08	0.78	0.68	0.81	2.22	0.3	2.159
W6047D	2.8	1.52	2.12	2.92	1.04	0.84	0.98	0.68	0.75	0.45	1.41
W6146D	4.4	1.5	2.16	2.21	1.56	1.53	0.67	0.79	1.25	0.61	1.668
W6246D	1.9	1.59	1.99	0.13	1.04	0.36	0.76	1.09	01	0.29	0.916
W6446D	1.9	1.68	3.08	1.3	1.72	1.22	1.53	1.36	1.64	1.25	1.668
W6545D	2.8	1.93	2.88	0.75	1.62	1.51	1.25	1.13	1.85	1.33	1.705
W6644	4.4	1.96	3.06	3.41	1.95	1.46	0.79	0.69	0.42	0.84	1.898
Average	4.0	1.8	2.50	1.88	1.64	1.10	1.16	0.99	1.33	0.75	1.723

Table 15. Surface nitrite concentration (mg l^{-1}) measured at the sampled stations from April 2002 to January 2003 with monthly and annual averages calculated for the whole stations respectively.

Month / Site #	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1S	0.2722	0.25	0.76			0.91	1.2	0.92	0.83	0.39	0.62
Hyper2	0.2591	0.26	0.73			0.96	1.15	0.92	0.84	0.38	0.62
W5749S	0.1513	0.18	0.47	0.8	0.74	0.6	1.15	0.93	1.01	0.65	0.61
W5850	0.0879	0.17	0.46	0.36	0.61	0.6	1.04	0.92	0.75	0.66	0.51
W5851	0.111	0.18	0.49	0.88	0.46	0.5	1.12	0.9	1.06	0.74	0.59
W5950S	0.0761	0.17	0.42	0.47	0.69	0.6	1.15	0.89	1.11	0.73	0.57
W6049	0.798	0.21	0.47	0.33	0.7	0.63	1.15	1	0.94	0.68	0.64
W6050	0.0806	0.15	0.44	1.02	0.58	0.61	1.01	0.91	1.04	0.68	0.61
W6074S	0.1562	06	0.42	1.52	0.54	0.56	1.07	0.92	1.06	0.81	0.67
W6146S	0.1547	0.23	0.3	0.82	0.64	0.69	1.23	0.94	0.95	0.65	0.60
W6246S	0.1931	0.24	0.47	05	0.76	0.38	1.41	0.97	0.97	0.63	0.52
W6446S	0.1675	0.25	0.46	0.53	0.8	0.67	1.29	1.02	0.97	0.37	0.58
W6545S	0.1623	0.26	0.48	0.14	0.8	0.7	1.31	0.99	0.96	0.23	0.52
W6644	0.1622	0.3	0.49	09	0.8	0.7	1.24	0.96	0.98	0.66	0.57
Average	0.20	0.20	0.49	0.58	0.67	0.65	1.18	0.94	0.96	0.59	0.59

Table 16. Near-bottom nitrite concentration (mg l^{-1}) measured at the sampled stations from April 2002 to January 2003 with monthly and annual averages calculated for the whole stations respectively.

Month / Site#	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1D	0.2592	0.26	0.59			0.94	1.08	0.91	0.84	0.4	0.65
W5749D	0.1564	0.21	0.47	0.45	0.65	0.67	0.87	0.46	1.03	0.66	0.56
W5950D	0.0797	0.15	0.35	0.52	0.58	0.41	0.51	0.67	1.05	0.68	0.49
W6047D	0.1484	0.35	0.37	0.92	0.45	0.45	0.59	0.43	0.39	0.65	0.47
W6146D	0.1546	0.28	0.38	0.24	0.6	0.67	0.34	0.45	0.56	0.97	0.46
W6246D	0.1618	0.24	0.38	0.12	0.5	0.36	0.63	0.56	01	0.99	0.39
W6446D	0.171	0.26	0.5	0.8	0.77	0.64	0.79	0.62	0.78	0.66	0.59
W6545D	0.1614	0.28	0.55	0.19	0.75	0.72	0.67	0.55	0.79	0.67	0.53
W6644	0.1622	0.28	0.5	0.17	0.86	0.71	0.4	0.33	0.25	0.5	0.41
Average	0.1616	0.25	0.45	0.42	0.64	0.61	0.65	0.55	0.63	0.68	0.50

Table 17. Surface calcium concentration (mg l^{-1}) measured at the sampled stations from April 2002 to January 2003 with monthly and annual averages calculated for the whole stations respectively.

Month / Site #	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1S	3563	3294	3333			2745	1452	1703	1797	1920	2622
Hyper2	3718	3392	3211			2708	1455	1691	1804	1891	2630
W5749S	3108	2690	2544	692	2349	2284	1364	1640	1687	1874	2096
W5850	3194	3061	2612	403	2142	2678	1352	1577	2059	1842	2174
W5851	3179	3346	2545	101	1964	2698	1364	1558	1682	1906	2108
W5950S	3208	3149	2702	1199	2373	2745	1344	1606	1706	1890	2286
W6049	3192	3296	2542	1107	2392	2695	1412	1370	1652	1953	2244
W6050	3218	2038	2680	1848	2431	2730	1335	1606	1695	1793	2226
W6074S	3148	766	2639	343	2469	2572	1710	1592	1705	1791	1891
W6146S	3123	3269	2514	1687	2396	2692	1407	1315	1609	1885	2276
W6246S	3106	3384	2497	1772	2468	1975	1409	1495	1647	1884	2247
W6446S	3143	3224	2483	1949	2421	2633	1408	1437	1658	1837	2309
W6545S	3150	3238	2438	2020	2410	3042	1411	1488	1702	1838	2369
W6644	3157	3306	2841	2013	2441	2971	1406	1537	1664	1891	2424
Average	3229	2960	2684	1261	2354	2655	1416	1543	1719	1871	2253

Table 18. Near-bottom calcium concentration (mg l^{-1}) measured at the sampled stations from April 2002 to January 2003 with monthly and annual averages calculated for the whole stations respectively.

Month / Site#	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1D	3574	3349	3312			2696	1463	1708	1775	1903	2472
W5749D	3101	3165	2530	2647	2403	2557	1788	2199	1720	1935	2404
W5950D	3186	2609	2754	2549	2498	2774	2272	2066	1713	2013	2443
W6047D	3019	3379	2655	2362	2571	2605	1950	2204	2233	2230	2520
W6146D	3226	3135	2644	2817	2548	2520	2107	2136	2012	2042	2518
W6246D	3176	3278	2651	2608	2486	2436	2071	2195	2484	2137	2552
W6446D	3162	3223	2521	2450	2558	2478	1904	1910	1896	2139	2424
W6545D	3133	3310	2516	2403	2428	2486	2028	2162	1852	2199	2451
W6644	3157	3236	2506	2474	2560	3098	2220	2347	2293	1934	2582
Average	3192	3187	2676	2538	2506	2628	1978	2103	1997	2059	2486

Table 19. Surface magnesium concentration (mg l^{-1}) measured at the sampled stations from April 2002 to January 2003 with monthly and annual averages calculated for the whole stations respectively.

Month / Site #	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1S	4729	5781	6040			4279	2272	2061	2058	2383	3904
Hyper2	4697	5938	5659			4100	2255	2050	2061	2403	3844
W5749S	3987	3602	3429	270	3702	3254	2246	1985	1988	2283	2722
W5850	3973	4043	3575	396	2718	4259	3659	1952	2664	2387	2885
W5851	4009	4375	3826	123	2701	4068	2234	1959	2012	2370	2827
W5950S	3978	4229	3758	1136	3394	4423	2071	2052	2024	2299	3032
W6049	3951	4301	3610	1026	3600	4084	2195	2145	1953	2350	3002
W6050	3993	2668	3739	2101	3114	4243	2182	2101	2029	2314	2922
W6074S	3962	867	4116	370	3092	4109	2904	1950	2045	2355	2540
W6146S	3888	4362	4191	1882	3458	4316	2244	2104	1852	2278	3147
W6246S	3894	4415	4051	1988	3648	3031	2217	2318	1939	2213	3055
W6446S	3890	4446	3912	2205	3845	4125	2334	2253	1807	2329	3201
W6545S	3937	4367	4079	2347	4107	4516	2341	2262	1977	2318	3323
W6644	3862	4373	4008	2326	2840	4862	2196	2194	1994	2378	3204
Average	4053	4126	4142	1347	3351	4119	2382	2099	2028	2332	3066

Table 20. Near-bottom magnesium concentration (mg l^{-1}) measured at the sampled stations from April 2002 to January 2003 with monthly and annual averages calculated for the whole stations respectively.

Month / Site#	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1D	4701	5619	6325			3929	2271	2039	2051	2413	3668
W5749D	3946	4216	3474	3456	3469	3829	2994	2788	2012	2311	3249
W5950D	3941	3577	3792	3249	3678	4474	3576	2649	2056	2591	3358
W6047D	3711	4556	3752	2928	3864	3926	3266	3317	2861	3022	3520
W6146D	3969	4249	4399	3669	3582	3785	3471	3215	2660	2624	3562
W6246D	3745	4354	4449	3371	3642	3920	3466	3270	3498	2776	3649
W6446D	3890	4408	3824	3049	4205	3725	3259	2943	2306	2993	3460
W6545D	3908	4471	4220	2957	3480	3771	3344	3131	2307	3102	3469
W6644	3862	4401	4127	3079	3819	4790	3665	3354	3192	2428	3671
Average	3963	4427	4262	3219	3717	4016	3256	2967	2549	2695	3507

Table 21. Total number of *Artemia* per litre counted in the surface samples collected from the sampled stations during the whole survey period from April 2002 to January 2003.

Month / Site#	April	May	June	July	August	September	November	December	January	Annual Average
Hyper1S	26	0	3	-	-	0	0	1	0	4.29
Hyper2	1	0	46	-	-	0	0	0	0	6.71
W5749S	4	3	1	0	0	0	0	0	0	0.89
W5850	23	0	5	0	0	0	0	0	0	3.11
W5851	60	0	4	0	0	0	0	0	0	7.11
W5950S	2	0	100	0	0	0	0	0	0	11.33
W6049	3	0	11	0	0	0	0	0	0	1.56
W6050	100	0	17	0	0	0	0	0	0	13.00
W6074S	0	1	6	0	0	0	0	0	0	0.78
W6146S	1	0	9	0	0	0	0	0	0	1.11
W6246S	23	2	14	0	0	0	0	0	0	4.33
W6446S	2	1	56	0	0	0	0	0	0	6.56
W6545S	3	0	98	0	0	0	0	0	0	11.22
W6644	21	8	56	0	0	0	0	0	0	9.44
Average	19.21	1.07	30.43	0	0	0	0	07	0	5.82

Table 22. Total number of *Artemia* numbers per litre counted in near bottom samples collected from the sampled stations during the whole sampling period from April 2002 to January 2003.

Month / Site#	April	May	June	July	August	September	October	November	December	January	Annual average
Hyper1D	35.0	0	13.0			0	0	0	0	0	6.0
W5749D	4.0	0	0	0	0	0	0	0	0	0	0.4
W5950D	23.0	5.0	0	0	0	0	0	0	0	0	2.8
W6047D	0	24.0	8.0	0	0	0	0	0	0	0	3.2
W6146D	1.0	0	15.0	0	0	0	0	0	0	0	1.6
W6246D	1.0	1.0	16.0	0	0	0	0	0	0	0	1.8
W6446D	1.0	3.0	42.0	0	0	0	0	0	0	0	4.6
W6545D	8.0	10	75.0	0	0	0	0	0	0	0	9.3
W6644	21.0	4.0	60	0	0	0	0	0	0	0	8.5
Average	10.4	5.2	25.4	0	0	0	0	0	0	0	4.1

Table 23. Total number of cysts per litre counted in the surface samples collected from the sampled stations during the whole survey period from April 2002 to January 2003.

Month / Site#	April	May	June	July	August	September	November	December	January	Annual Average
Hyper1S	500	0	0			0	0	0	0	71
Hyper2	333	166	0			0	0	0	0	71
W5749S	167	333	0	0	0	0	0	0	0	56
W5850	2333	4000	0	0	0	0	0	0	0	704
W5851	833	333	0	0	0	0	0	0	0	130
W5950S	0	833	0	0	500	0	0	0	0	148
W6049	667	333	0	166	0	0	0	0	0	130
W6050	833	167	0	0	0	0	0	0	0	111
W6074S	0	333	0	0	0	0	0	0	0	37
W6146S	0	0	0	0	0	0	0	0	0	0
W6246S	333	333	0	166	0	0	0	0	0	93
W6446S	333	333	0	0	0	0	0	0	0	74
W6545S	1167	1500	0	166	0	0	0	0	0	315
W6644	500	1667	0	0	0	0	0	0	0	241
Average	571.43	738.05	00	41.50	41.67	00	00	00	00	156

Table 24. Total number of cysts number per litre counted in near-bottom samples collected from the sampled stations during the survey period from April 2002 to January 2003.

Month / Site#	April	May	June	July	August	September	October	November	December	January	Annual Average
Hyper1D	333.3	166.7	0			0	0	0	2.0	5.0	0
W5749D	166.7	333.3	0	0	0	0	0	0	0	0	0
W5950D	166.7	1166.7	0	0	0	0	0	0	0	0	0
W6047D	166.7	166.7	0	166.7	0	0	0	0	0	0	0
W6146D	333.3	2833.3	0	0	0	0	0	0	0	0	0
W6246D	1500	0	0	0	0	0	0	0	1.0	0	0
W6446D	166.7	1166.7	0	0	0	0	0	0	0	1.0	0
W6545D	1500	500	0	0	0	0	0	0	0	0	0
W6644	500	1000	0	0	0	0	0	0	0	0	0
Average	537.0	814.8	0	20.8	0	0	0	0	0.3	0.7	0

Table 25. Correlation matrix showing Pearson Product Moment Correlation Coefficients (**bold**) and their P values (*italics*) for *Artemia*, *Artemia* cysts, and all environmental variables for both sampling depths for surface and near-bottom water samples during the study. n = 219 - 224.

	Correlation coefficients and P values										
Variable	***Artemia***	**Temp.**	**Salinity**	**pH**	**Nitrite**	**Nitrate**	**Ammonia**	**Phosphate**	**Calcium**	**Magnesium**	**Cysts**
Artemia		R=**0.16** *p=0.0175*	**0.184** *0.00569*	**-0.324** *>0.0001*	**-0.225** *>0.0007*	**0.313** *>0.0001*	**0.085** *0.208*	**0.329** *>0.0001*	**0.274** *>0.0001*	**0.269** *>0.0001*	**0.105** *0.118*
Temperature	R=**0.16** *p=0.0175*		**0.260** *0.0001*	**-0.523** *>0.0001*	**-0.447** *>0.0001*	**0.213** *0.002*	**-0.04** *0.552*	**-0.0142** *0.834*	**0.490** *>0.0001*	**0.546** *>0.0001*	**0.153** *0.024*
Salinity	**0.184** *0.00569*	**0.260** *0.0001*		**-0.283** *>0.0001*	**-0.370** *>0.0001*	**0.140** *0.036*	**0.093** *0.165*	**0.182** *0.006*	**0.542** *>0.0001*	**0.556** *>0.0001*	**0.108** *>0.106*
pH	**-0.324** *>0.0001*	**-0.523** *>0.0001*	**-0.283** *>0.0001*		**0.643** *>0.0001*	**-0.183** *0.006*	**-0.275** *>0.0001*	**-0.354** *>0.0001*	**-0.498** *>0.0001*	**-0.450** *>0.0001*	**-0.235** *>0.0005*
Nitrite	**-0.225** *>0.0007*	**-0.447** *>0.0001*	**-0.370** *>0.0001*	**0.643** *>0.0001*		**-0.146** *0.029*	**-0.362** *>0.0001*	**-0.422** *>0.0001*	**-0.660** *>0.0001*	**-0.504** *>0.0001*	**-0.367** *>0.0001*
Nitrate	**0.313** *>0.0001*	**0.213** *0.002*	**0.140** *0.036*	**-0.183** *0.006*	**-0.146** *0.029*		**-0.0507** *0.450*	**0.368** *>0.0001*	**0.199** *0.003*	**0.126** *0.060*	**0.158** *0.018*
Ammonia	**0.085** *0.208*	**-0.04** *0.552*	**0.093** *0.165*	**-0.275** *>0.0001*	**-0.362** *>0.0001*	**-0.051** *0.450*		**0.664** *>0.0001*	**0.265** *>0.0001*	**0.182** *0.006*	**0.101** *0.130*
Phosphate	**0.329** *>0.0001*	**-0.0142** *0.834*	**-0.354** *>0.0001*	**-0.354** *>0.0001*	**-0.422** *>0.0001*	**0.368** *>0.0001*	**0.664** *>0.0001*		**0.256** *0.0001*	**0.171** *0.010*	**0.137** *0.040*
Calcium	**0.274** *>0.0001*	**-0.0142** *0.834*	**-0.498** *>0.0001*	**-0.498** *>0.0001*	**-0.660** *>0.0001*	**0.199** *0.003*	**0.265** *>0.0001*	**0.256** *0.0001*		**0.913** *>0.0001*	**0.275** *>0.0001*
Magnesium	**0.269** >0.0001	**0.546** *>0.0001*	**-0.450** *>0.0001*	**-0.450** *>0.0001*	**-0.504** *>0.0001*	**0.126** *0.060*	**0.182** *0.006*	**0.171** *0.010*	**0.913** *>0.0001*		**0.245** *0.0002*
Cysts	**0.105** *0.118*	**0.153** *0.024*	**0.108** *>0.106*	**-0.235** >0.0005	**-0.367** *>0.0001*	**0.158** *0.018*	**0.101** *0.130*	**0.137** *0.040*	**0.275** *>0.0001*	**0.245** *0.0002*	

Table 26. Correlation matrix showing Pearson Product Moment Correlation Coefficients (**bold**) and their P values (*italics*) for *Artemia*, *Artemia* cysts, and all environmental variables for surface water samples during the study. n = 132 - 136.

	Correlation coefficients and P values										
Variable	***Artemia***	**Temp.**	**Salinity**	**pH**	**Nitrite**	**Nitrate**	**Ammonia**	**Phosphate**	**Calcium**	**Magnesium**	**Cysts**
Artemia		R=**0.191** *p=0.0281*	**0.220** *0.001*	**-0.354** *>0.0001*	**-0.261** *>0.0007*	**0.252** *0.003*	**0.185** *>0.031*	**0.382** *>0.0001*	**0.287** *>0.0001*	**0.277** *>0.001*	**0.127** *0.140*
Temperature	R=**0.191** *p=0.0281*		**0.267** *0.002*	**-0.672** *>0.0001*	**-0.498** *>0.0001*	**0.276** *0.001*	**0.065** *0.457*	**0.169** *0.052*	**0.454** *>0.0001*	**0.499** *>0.0001*	**0.188** *0.031*
Salinity	**0.220** *0.001*	**0.267** *0.002*		**-0.244** *>0.005*	**-0.350** *>0.0001*	**0.198** *0.021*	**0.108** *0.212*	**0.238** *0.005*	**0.541** *>0.0001*	**0.571** *>0.0001*	**0.097** *>0.260*
pH	**-0.354** *>0.0001*	**-0.672** *>0.0001*	**-0.244** *>0.005*		**0.650** *>0.0001*	**-0.249** *0.004*	**-0.218** *>0.011*	**-0.309** *>0.0003*	**-0.484** *>0.0001*	**-0.430** *>0.0001*	**-0.258** *>0.003*
Nitrite	**-0.261** *>0.0007*	**-0.498** *>0.0001*	**-0.350** *>0.0001*	**0.650** *>0.0001*		**-0.189** *0.027*	**-0.384** *>0.0001*	**-0.465** *>0.0001*	**-0.639** *>0.0001*	**-0.480** *>0.0001*	**-0.383** *>0.0001*
Nitrate	**0.252** *0.003*	**0.276** *0.001*	**0.198** *0.021*	**-0.249** *0.004*	**-0.189** *0.027*		**0.085** *0.325*	**0.486** *>0.0001*	**0.174** *0.042*	**0.149** *0.083*	**0.137** *0.113*
Ammonia	**0.185** *>0.031*	**0.065** *0.457*	**0.108** *0.212*	**--0.218** *>0.011*	**-0.384** *>0.0001*	**0.085** *0.325*		**0.661** *>0.0001*	**0.360** *>0.0001*	**0.249** *>0.004*	**0.171** *0.046*
Phosphate	**0.382** *>0.0001*	**0.169** *0.052*	**0.238** *0.005*	**-0.309** *>0.0003*	**-0.465** *>0.0001*	**0.486** *>0.0001*	**0.661** *>0.0001*		**0.305** *0.0003*	**0.220** *0.010*	**0.178** *0.039*
Calcium	**0.287** *>0.0001*	**0.454** *>0.0001*	**0.541** *>0.0001*	**--0.484** *>0.0001*	**-0.639** *>0.0001*	**0.174** *0.042*	**0.360** *>0.0001*	**0.305** *0.0003*		**0.926** *>0.0001*	**0.369** *>0.0001*
Magnesium	**0.277** *>0.001*	**0.499** *>0.0001*	**0.571** *>0.0001*	**-0.430** *>0.0001*	**-0.480** *>0.0001*	**0.149** *0.083*	**0.249** *>0.004*	**0.220** *0.010*	**0.926** *>0.0001*		**0.255** *>0.003*
Cysts	**0.127** *0.140*	**0.188** *0.031*	**0.097** *>0.260*	**--0.258** *>0.003*	**-0.383** *>0.0001*	**0.158** *0.018*	**0.171** *0.046*	**0.178** *0.039*	**0.369** *>0.0001*	**0.255** *>0.003*	

Table 27. Correlation matrix showing Pearson Product Moment Correlation Coefficients (**bold**) and their P values (*italics*) for *Artemia*, *Artemia* cysts, and all environmental variables for surface water samples during April-June. N = 38.

	Correlation coefficients and P values										
Variable	***Artemia***	**Temp.**	**Salinity**	**pH**	**Nitrite**	**Nitrate**	**Ammonia**	**Phosphate**	**Calcium**	**Magnesium**	**Cysts**
Artemia	-	**-0.077** *0.6468*	**0.064** *0.7036*	**-0.059** *0.7273*	**0.155** *0.3564*	**0.106** *0.5307*	**0.158** *0.3473*	**0.230** *0.1667*	**-0.086** *0.6095*	**-0.033** *0.8447*	**-0.075** *0.6569*
Temperature	**-0.077** *0.6468*	-	**0.171** *0.3081*	**-0.396** *0.0132*	**0.111** *0.5111*	**0.112** *0.5052*	**-0.603** *<0.0001*	**-0.094** *0.5764*	**-0.662** *<0.0001*	**-0.366** *0.0231*	**-0.181** *0.280*
Salinity	**0.064** *0.7036*	**0.171** *0.3081*	-	**-0.248** *0.1337*	**0.039** *0.8175*	**0.127** *0.4496*	**0.019** *0.9097*	**0.100** *0.5519*	**-0.083** *0.6232*	**0.138** *0.4100*	**-0.269** *0.1031*
pH	**-0.059** *0.7273*	**-0.396** *0.0132*	**-0.248** *0.1337*	-	**-0.563** *0.0002*	**0.159** *0.3438*	**0.337** *0.0379*	**0.271** *0.0997*	**0.285** *0.0827*	**-0.223** *0.1806*	**0.374** *0.0202*
Nitrite	**0.155** *0.3564*	**0.111** *0.5111*	**0.039** *0.8175*	**-0.563** *0.0002*	-	**0.026** *0.8782*	**0.064** *0.7049*	**-0.19** *0.2543*	**-0.158** *0.3448*	**0.084** *0.6176*	**-0.290** *0.0771*
Nitrate	**0.106** *0.5307*	**0.112** *0.5052*	**0.127** *0.4496*	**0.159** *0.3438*	**0.026** *0.8782*	-	**0.246** *0.1379*	**0.713** *<0.0001*	**-0.572** *0.0001*	**-0.722** *<0.0001*	**-0.085** *0.6134*
Ammonia	**0.158** *0.3473*	**-0.603** *<0.0001*	**0.019** *0.9097*	**0.337** *0.0379*	**0.064** *0.7049*	**0.246** *0.1379*	-	**0.510** *0.0009*	**0.279** *0.0903*	**0.018** *0.9141*	**0.059** *0.7261*
Phosphate	**0.230** *0.1667*	**-0.094** *0.5764*	**0.100** *0.5519*	**0.271** *0.0997*	**-0.19** *0.2543*	**0.713** *<0.0001*	**0.510** *0.0009*	-	**-0.505** *0.0010*	**-0.690** *<0.0001*	**-0.088** *0.6004*
Calcium	**-0.086** *0.6095*	**-0.662** *<0.0001*	**-0.083** *0.6232*	**0.285** *0.0827*	**-0.158** *0.3448*	**-0.572** *0.0001*	**0.279** *0.0903*	**-0.505** *0.0010*	-	**0.804** *<0.0001*	**0.248** *0.1341*
Magnesium	**-0.033** *0.8447*	**-0.366** *0.0231*	**0.138** *0.4100*	**-0.223** *0.1806*	**0.084** *0.6176*	**-0.722** *<0.0001*	**0.018** *0.9141*	**-0.690** *<0.0001*	**0.804** *<0.0001*	-	**0.043** *0.8003*
Cysts	**-0.075** *0.6569*	**-0.181** *0.280*	**-0.269** *0.1031*	**0.374** *0.0202*	**-0.290** *0.0771*	**-0.085** *0.6134*	**0.059** *0.7261*	**-0.088** *0.6004*	**0.248** *0.1341*	**0.043** *0.8003*	-

Table28. Correlation matrix showing Pearson Product Moment Correlation Coefficients (**bold**) and their P values (*italics*) for *Artemia*, live *Artemia* cysts, and all environmental variables for near-bottom water samples during the study. n = 87 - 88.

	Correlation coefficients and P values										
Variable	*Artemia*	Temp.	Salinity	pH	Nitrite	Nitrate	Ammonia	Phosphate	Calcium	Magnesium	Cysts
Artemia		**0.154** *0.154*	**0.139** *0.196*	**-0.330** *>0.002*	**-0.182** *0.09*	**0.476** *>0.0001*	**0.011** *0.92*	**0.237** *0.026*	**0.322** *>0.002*	**0.335** *>0.001*	**0.047** *0.661*
Temperature	**0.154** *0.154*		**0.185** *0.086*	**-0.223** *>0.038*	**-0.302** *0.005*	**0.257** *0.016*	**-0.275** *0.01*	**-0.351** *>0.001*	**0.531** *>0.0001*	**0.612** *>0.0001*	**0.108** *>0.0001*
Salinity	**0.139** *0.196*	**0.185** *0.086*		**--0.289** *0.007*	**-0.349** *>0.0009*	**0.152** *0.158*	**-0.026** *0.807*	**0.041** *0.706*	**0.510** *>0.0001*	**0.484** *>0.0001*	**0.134** *>0.0001*
pH	**-0.330** *>0.002*	**-0.223** *>0.038*	**--0.289** *0.007*		**0.565** *>0.0001*	**-0.243** *0.024*	**-0.252** *0.018*	**-0.409** *>0.0001*	**-0.442** *>0.0001*	**-0.404** *>0.0001*	**-0.204** *>0.058*
Nitrite	**-0.182** *0.09*	**-0.302** *0.005*	**-0.349** *>0.0009*	**0.565** *>0.0001*		**-0.224** *0.036*	**-0.271** *0.011*	**-0.295** *0.005*	**-0.659** *>0.0001*	**-0.477** *>0.0001*	**-0.366** *0.0005*
Nitrate	**0.476** *>0.0001*	**0.257** *0.016*	**0.152** *0.158*	**-0.243** *0.024*	**-0.224** *0.036*		**-0.042** *0.700*	**0.288** *0.006*	**0.444** *0.042*	**0.257** *0.016*	**0.200** *0.062*
Ammonia	**0.011** *0.92*	**-0.275** *0.01*	**-0.026** *0.807*	**-0.252** *0.018*	**-0.271** *0.011*	**-0.042** *0.700*		**0.724** *>0.0001*	**0.013** *0.903*	**-0.066** *0.540*	**0.045** *0.677*
Phosphate	**0.237** *0.026*	**-0.351** *>0.001*	**0.041** *0.706*	**-0.409** *>0.0001*	**-0.295** *0.005*	**0.288** *0.006*	**0.724** *>0.0001*		**0.084** *0.439*	**-0.013** *0.904*	**0.066** *0.543*
Calcium	**0.322** *>0.002*	**0.531** *>0.0001*	**0.510** *>0.0001*	**-0.442** *>0.0001*	**-0.659** *>0.0001*	**0.444** *0.042*	**0.013** *0.903*	**0.084** *0.439*		**0.844** *>0.0001*	**0.446** *>0.0001*
Magnesium	**0.335** *>0.001*	**0.612** *>0.0001*	**0.484** *>0.0001*	**-0.404** *>0.0001*	**-0.477** *>0.0001*	**0.257** *0.016*	**-0.066** *0.540*	**-0.013** *0.904*	**0.844** *>0.0001*		**0.253** *>0.017*
Cysts	**0.047** *0.661*	**0.108** *>0.0001*	**0.134** *>0.0001*	**-0.204** *>0.058*	**-0.366** *0.0005*	**0.200** *0.062*	**0.045** *0.677*	**0.066** *0.543*	**0.446** *>0.0001*	**0.253** *>0.017*	

Table 29. Correlation matrix showing Pearson Product Moment Correlation Coefficients (**bold**) and their P values (*italics*) for *Artemia*, *Artemia* cysts, and all environmental variables for near-bottom water samples during April- June only. n = 64 - 69.

	Correlation coefficients and P values										
Variable	***Artemia***	**Temp.**	**Salinity**	**pH**	**Nitrite**	**Nitrate**	**Ammonia**	**Phosphate**	**Calcium**	**Magnesium**	**Cysts**
Artemia		**-0.051** *0.691*	**0.011** *0.927*	**-0.124** *0.321*	**0.212** *0.080*	**0.174** *0.153*	**0.30** *0.805*	**0.210** *0.084*	**-0.108** *0.379*	**-0.001** *0.991*	**-0.124** *0.311*
Temperature	**-0.051** *0.691*		**0.173** *0.172*	**-0.510** *<0.0001*	**-0.328** *0.008*	**-0.145** *0.253*	**-0.499** *<0.0001*	**-0.254** *<0.042*	**0.523** *<0.0001*	**-0.032** *0.800*	**-0.180** *0.154*
Salinity	**0.011** *0.927*	**0.173** *0.172*		**--0.335** *0.006*	**0.249** *0.039*	**0.052** *0.671*	**-0.128** *0.295*	**-0.034** *0.782*	**0.149** *0.221*	**0.450** *0.0001*	**-0.238** *0.049*
pH	**-0.124** *0.321*	**-0.510** *<0.0001*	**--0.335** *0.006*		**-0.667** *<0.0001*	**0.177** *0.155*	**0.306** *0.012*	**0.227** *0.067*	**0.265** *<0.032*	**-0.400** *0.0008*	**0.396** *0.001*
Nitrite	**0.212** *0.080*	**-0.328** *0.008*	**0.249** *0.039*	**-0.667** *<0.0001*		**-0.075** *0.541*	**-0.195** *0.108*	**-0.209** *0.085*	**-0.158** *0.194*	**0.325** *0.006*	**-0.325** *0.006*
Nitrate	**0.174** *0.153*	**-0.145** *0.253*	**0.052** *0.671*	**-0.177** *0.155*	**-0.075** *0.541*		**0.267** *0.027*	**0.676** *<0.0001*	**-0.270** *<0.025*	**-0.421** *0.025*	**-0.107** *0.383*
Ammonia	**0.30** *0.805*	**-0.499** *<0.0001*	**-0.128** *0.295*	**0.306** *0.012*	**-0.195** *0.108*	**0.267** *0.027*		**0.470** *<0.0001*	**0.262** *<0.029*	**-0.044** *0.721*	**0.066** *0.591*
Phosphate	**0.210** *0.084*	**-0.254** *<0.042*	**-0.034** *0.782*	**0.227** *0.067*	**-0.209** *0.085*	**0.676** *<0.0001*	**0.470** *<0.0001*		**-0.354** *0.003*	**-0.525** *<0.0001*	**-0.102** *0.406*
Calcium	**-0.108** *0.379*	**0.523** *<0.0001*	**0.149** *0.221*	**0.265** *<0.032*	**-0.158** *0.194*	**-0.270** *0.025*	**0.262** *0.029*	**-0.354** *0.003*		**0.702** *<0.0001*	**0.217** *0.074*
Magnesium	**-0.001** *0.991*	**-0.032** *0.800*	**0.450** *0.0001*	**-0.400** *0.0008*	**0.325** *0.006*	**-0.421** *0.025*	**-0.044** *0.721*	**-0.525** *<0.0001*	**0.702** *<0.0001*		**-0.055** *0.652*
Cysts	**-0.124** *0.311*	**-0.180** *0.154*	**-0.238** *0.049*	**0.396** *0.001*	**-0.325** *0.006*	**-0.107** *0.383*	**0.066** *0.591*	**-0.102** *0.406*	**0.217** *0.074*	**-0.055** *0.652*	

Table.30. Mean life-spans of *Artemia* sp. grown under variable environmental conditions of temperature, pH, food source, and salinity + standard deviations. N = 9

Temperature °C	**Life-span (days)**	**pH**	**Life-span (days)**	**Food source**	**Life-span (days)**	**Salinity (ppt)**	**Life-span (days)**
15	6±5.9	7.5	2.1±0.3	Chl	3.9±5.4	75	7.7±7.5
25	4.3±6.3	8	4.0±6.0	Dun	4.1±6.7	100	4.4±5.3
30	5.3±7.6	9	1.1±0.3	TS	1.0±0.0	125	1.0±0.0
40	1±0.0	9.5	1.6±1.7	Yeast	4.1±5.9	150	1.1±0.3
		10	1.2±0.4			200	1.0±0.0

Table.31. Comparison of *Artemia* sp. tolerance under different temperature (°C) in days by Fisher's PLSD and the non-parametric Kruskal-Wallis test. N = 9

	Kruskal-Wallis		Fisher's PLSD – P-Values			
T (°C)	**Sum Ranks**	**Mean Ranks**	**15**	**25**	**30**	**40**
15	208.0	23.1	-	0.5418	0.8068	0.0736
25	182.0	20.2	0.5418	-	0.7138	0.2265
30	177.0	19.7	0.8068	0.7138	-	0.1187
40	99.0	11.0	0.0736	0.2265	0.1187	-

Table. 32. Comparison of *Artemia* sp. tolerance under different range of pH in days by Fisher's PLSD and the non-parametric Kruskal-Wallis test. N = 9

	Kruskal-Wallis		Fisher's PLSD – P-Values				
pH	**Sum Ranks**	**Mean Ranks**	**7.5**	**8**	**9**	**9.5**	**10**
7.5	306.0	34.0	-	0.1627	0.4559	0.6780	0.5072
8	287.0	31.9	0.1627	-	***0.0356***	0.0731	***0.0429***
9	137.0	15.2	0.4559	***0.0356***	-	0.7397	0.9337
9.5	148.0	16.4	0.6780	0.0731	0.7397	-	0.8031
10	157.0	17.4	0.5072	***0.0429***	0.9337	0.8031	-

Table. 33. Comparison of *Artemia* sp. tolerance under different type of food in days by Fisher's PLSD and the non-parametric Kruskal-Wallis test. N = 9

	Kruskal-Wallis		Fisher's PLSD – P-Values			
Food source	**Sum Ranks**	**Mean Ranks**	**Chl**	**Dun**	**TS**	**Yeast**
Chl	183.5	20.4	-	0.9285	0.2482	0.9285
Dun	169.0	18.8	0.9285	-	0.2144	0.0
TS	130.5	14.5	0.2482	0.2144	-	0.2144
Yeast	183.0	20.3	0.9285	0.0	0.2144	-

Table. 34. Comparison of *Artemia* sp. under different range of salinity (ppt) in days by Fisher's PLSD and the non-parametric Kruskal-Wallis test. N = 9

	Kruskal-Wallis		Fisher's PLSD – P-Values				
Salinity (ppt)	**Sum Ranks**	**Mean Ranks**	**75**	**100**	**125**	**150**	**200**
75	296.5	32.9	-	0.1045	***0.0014***	***0.0016***	***0.0014***
100	248.0	27.6	0.1045	-	0.0834	0.0934	0.0834
125	157.5	17.5	***0.0014***	0.0834	-	0.9546	0.0
150	175.5	19.5	***0.0016***	0.0934	0.9546	-	0.9546
200	157.5	17.5	***0.0014***	0.0834	0.0	0.9546	-

الملخص العربي

جامعة الإمارات العربية المتحدة
عمادة الدراسات العليا
برنامج ماجستير علوم البيئة

عنوان الرسالة

تقييم إنتاجية ربيان الملح (*Artemia* sp.) في بحيرة الوثبة أبوظبي، دولة الإمارات العربية المتحدة

مقدمة من

شيخة سالم عبيد الظاهري
بكالوريوس علوم الغذاء والتغذية
كلية الزراعة، جامعة الإمارات العربية المتحدة (2000)

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د. وليد حمزة رئيس قسم علوم الحياة كلية العلوم، جامعة الإمارات العربية المتحدة	أ.د. عبدالفتاح السيد كلية نظم الأغذية جامعة الإمارات العربية المتحدة	د. ريتشارد بيري باحث أول هيئة أبحاث البيئة والحياة الفطرية وتنميتها

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