Ecological Assessment of Re-flooded Mesopotamian Marshes (Iraq)

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Sama AlMaarofi

ABSTRACT

Assessing the ecological characteristics (water quality and the biological functions) of the Mesopotamian marshes is necessary to evaluate their recovery. Mesopotamian marshes have been affected by several anthropogenic impacts and providing a sufficient water supply is a challenge. Among the several anthropogenic activities that have caused damage to the Mesopotamian ecosystem, water shortage (mainly since 1974) and desiccation (from 1993 to 2003) have caused the most damage. In a case like Mesopotamia, it is important to quantify the damage in order to design a recovery plan and suitable recovery methods.

The main goal of my thesis is to define the current hydrological and ecological status of the Mesopotamian marshes after re-flooding, in order to understand and identify the factors that are limiting their recovery to historical conditions. The main objectives of my research are: 1) investigate the changes in discharge and salinity of the main water sources to the Mesopotamian marshes (the Tigris and Euphrates Rivers) over time and how any changes may be affecting water quality; 2) identify the main sources of increased salinity of the marshes after re-flooding; 3) identify the major parameters affecting the water quality Mesopotamia marshes after re-flooding; and 4) investigate whether there are differences in species composition and abundance in phytoplankton communities among the selected re-flooded marshes of Al-Hawizeh, a marsh located in the north-east of the Mesopotamian marsh system, and what environmental parameters relate to those differences.

My results indicate that ~ 45% of the annual water discharge of the Tigris and Euphrates Rivers was lost by 2002 and that there was a significant shift in the period of maximum water discharge from spring (March) during 1973 to summer (June and July) during 2002 – 2005 and to fall (November) during 2006 – 2007. They also indicate that the average water salinity of the two rivers in 2006 – 2007 was 0.73 practical salinity unit (psu) which is 1.9 times greater than their historical level (0.4psu).

The Mesopotamian marshes increased in salinity from their historical level, 0.4 psu, to 2.5 psu during 1980s and then declined to 1.1 psu after re-flooding. The high salinity values observed, especially early in the inundation, were from re-dissolution of salts that accumulated during the desiccation period, while the persistent increase relative to historical values is mainly due to increase the salinity of the inflowing rivers and longer water residence in the marshes. However, re-dissolution of salts can be added to the main reasons of increasing salinity of the Al-Hammar marsh. The results show that there was a net loss of salt from Al-Hawizeh marsh, and a net gain in salt for Hammar Marsh. In both cases, the change was in large part due to changes in water level. The salt budget for Central Marsh was problematical, probably because the water flows in and out of some distributaries were hard to quantify.

Based on water quality indices combining several parameters (dissolved oxygen, nitrate, and pH), changes in water quality from prior to the desiccation period (historical state) to after re-flooding were generally moderate. However, deterioration in water quality of the re-flooded marshes is evident when salinity related parameters, specifically total dissolved solids, chloride and sulphate, are included in the water quality index calculation. Marshes that were severely damaged by desiccation and construction of embankments during the war, Majnoon and Lissan Ijerda, show low potential of recovery compared to marshes that are close to the river inputs.

The Al-Hawizeh marsh complex was investigated as a case study for biological assessment. I identified significant spatial differences among individual marshes within Al-Hawizeh suggesting that their once homogenous nature has been altered since inundation in 2003. Silicate concentrations in Al-Hawizeh marsh were 10 times lower than before desiccation. Since silicate is an important nutrient for diatoms, this may be a driver of phytoplankton community structure in the marshes. A change from abundant Bacillariophyta during the pre-desiccation period to Chlorophyta after re-flooding could be due to reduction in SiO_2 concentrations, especially in areas far from the major water inputs. The biological assessment of Al-Hawizeh marsh revealed three important issues: 1) invasion of euryhaline species of phytoplankton, which could reflect increasing salinity over time; 2) harmful species were recorded in small abundance (<1000 cell/ml), which could be a source of serious health issues; and 3) an increase of approximately 100 times in Cyanobacteria over the historical record, which can be attributed to high nutrient levels, especially in the southern marshes of Al-Hawizeh.

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DEDICATION

To my beloved husband, Dr. Ali Douabul, who is always supporting me and encouraging me with his best wishes and kindness. He was and is still always there cheering me up, and standing by me through the good times and bad.

Dear Ari…

Like a candle burning bright
Love is glowing in your eyes
A flame to light our way
That burns brighter everyday
But now I have you
Nobody loves me like you do

Like a leaf upon the wind
I could find no place to land
I dreamed the hours away
And wondered everyday
Do dreams come true
And nobody loves me like you do
"DUNNE, JAMES &OLAND, PAMELA"

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LIST OF ABBREVIATIONS

AAS	Anthropogenic associated salinity
BA	Biological Assessment
BOD	Biological oxygen demand
Ca^{+2}	Calcium
Chl *a*	Chlorophyll *a*
Cl^-	Chloride
CM	Central marsh
CWQI	Canadian Water Quality Index
DO	Dissolved oxygen
EA	Ecological assessment
EC	Electrical conductivity
HM	Al-Hammar marsh
HCO_3^-	Bicarbonate
HZ	Al-Hawizeh marsh
K^+	Potassium
Km^2	Square kilometre
LP	Light penetration
Mg^{+2}	Magnesium
MOD	Main Outfall Drain
MoWR	Ministry of Water Resources
Na^-	Sodium
NAS	Natural associated salinity
NO_2^-	Nitrite
NO_3^-	Nitrate
ppm	Part per million
ppt	Part per thousand
psu	Practical salinity unit
PCA	Principal Component analysis
PRC	Principal Response curve
SiO_2	Silicate
SO_4^{-2}	Sulphate
SRP	Soluble Reactive Phosphate
TDS	Total dissolved solids
TSS	Total suspended solids
TWPCR	Turkish Water Pollution Control Regulation
USEPA	U.S. Environmental Protection Agency
WCD	Water Column Depth
WD	Water discharge
WEA	Wetland ecological assessment
WQA	Water quality assessment
WQI	Water quality index
WQP(s)	Water quality parameter(s)
WMP	Water management plan
WTW	Wissenschaftlich-Technische Werkstätten

Chapter 1

Introduction to Ecological Assessment:

Mesopotamian Marshes Case Study

1.1 Introduction

1.1.1 Mesopotamian Marshes

The Mesopotamian marshes, in southern Iraq (29°55’00”N to 32°45’00”N and 45°25’00”E to 48°30’00”E) are the biggest complex of wetlands in Iraq and one of the most important aquatic systems in the Middle East (Scott 1995, Partow 2001, IMET 2006). These distinctive ecosystems historically sustained several important habitats that provided resources for local communities and maintained significant populations of wildlife, including endemic and endangered aquatic and semi-aquatic species (Scott 1995, Partow 2001). The present Mesopotamia developed around 5,000 B.C. (Aqrawi 1994). These wetlands were the location of some of the world’s first recorded civilizations such as Ur, (~4500-3800 B.C.), Sumer (~3000-2000 B.C.), and Babylon (~703 B.C.; Wali 1994). The descendants of these ancient populations are now called Al-Maadan or Marsh Arabs, and they are completely dependent on marsh resources, such as reeds, water buffalo, and fish, to fulfil their needs. Crop-based agriculture on the edges of the marshes also supports the life of the Marsh Arabs.

Water supply to the marshes has fluctuated with the discharge of the Tigris and the Euphrates Rivers through the centuries and with the ability of Iraqi rulers to control water distribution, given the area's unique geology and seasonality (Rzoska 1980). The Mesopotamian marshes consist of three large marsh complexes: Al-Hawizeh, Central, and Al-Hammar (Figure 1–1). The Al-Hawizeh marshes are located in the southeast of Iraq and straddle the Iraq-Iran border. They lie south of Al-Msharah village in Al-Amarah City and extend south to Al-Qurna village in Al-Basra City (Figure 1–1). The Al-Hawizeh marshes used to occupy an area of about 2350 km^2 of permanent sub-marshes and had large open water areas during the flood season. The Central marshes are bordered by the Tigris River to the east and the Euphrates River to the south with Al-Nasiriya City located on the south western edge of the marsh and the village of Qalat Saleh on the south east (Figure 1–1). The Central marshes originally occupied an approximate area of 3000 km^2 of seasonally flooded sub-marshes and large open water bodies. The Al-

Hammar marshes extend from Al-Nasiriya City in the west to the junction of the Tigris and Euphrates Rivers at Garmatt Ali village in Al-Basra City (Figure 1–1). The Al-Hammar marshes historically occupied approximately 3000 km^2expanding to over 4500 km^2 during seasonal floods. Downstream of the marshes, the Tigris and Euphrates Rivers join to form the Shatt Al-Arab River at Garmatt Ali village and flow towards the Arabian Gulf.

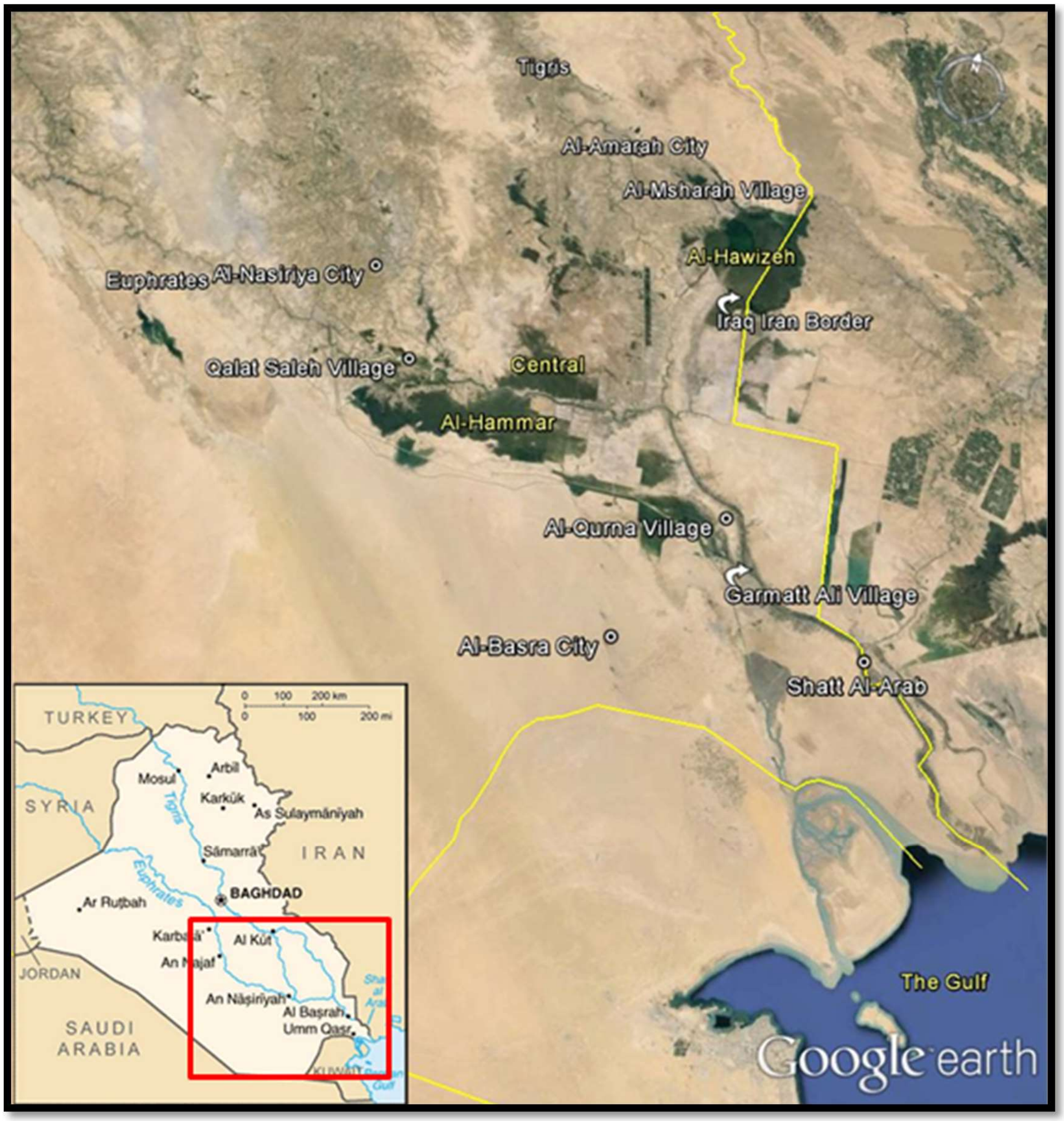


Figure 1–1: Location of the Mesopotamian marshes. Source: Medic Evolved (2006) and US Department of States Geographer.

1.1.2 Water Resources of the Mesopotamian Marshes

The Tigris and the Euphrates Rivers are the main water resources for the Mesopotamian marshes (IMET 2006; Figure 1–2). Their origins are in northeastern Turkey, where the Tigris River originates from Hazar Lake and the Euphrates River originates at Mount Ararat near Lake Van (Rzoska 1980). The plentiful snowmelt and heavy rainfall that occurs in the mountains around Turkey, Syria, Iraq, and Iran provide seasonal water pulses into these two rivers (Rzoska 1980). The Tigris River receives 44% of its water from Turkey and 56% of its flow arises from left-bank tributaries in Iraq including the Greater Zab, Lesser Zab, Al-Adhaim and Diyala Rivers (IMET 2006). The Euphrates River collects 88% of its flow in Turkey and 12% in Syria, with no water input from within Iraq (IMET 2006). The Tigris River runs over carbonate-derived soils and bedrock, while the Euphrates River runs from Turkey passing through Syria into Iraq through desert and gypsum-rich soils (IMET 2006).

In the southern part of Iraq, two main distributaries of the Tigris River, the Al-Msharah and the Al-Kahla Rivers, are the main water inputs into Al-Hawizeh marsh. In addition, the northeastern part of the Al-Hawizeh marsh receives seasonal water input from Iran via two distributaries of the Al-Karkheh River. The Central marsh is fed by one branch of the Tigris River, the Al-Garraf River, while the western part of the Central marsh is fed by several canals from the Euphrates River. Precipitation, especially in late fall and early spring (November to March), contributes to the water supply of the marsh; however, its supply is relatively low, less than 200 mm annually (Hussain 1994). Groundwater sources are not believed to discharge into the Mesopotamian marshes (Hussain 1994) as during the desiccation period from 1993 to 2003 no evidence of groundwater recharge was observed.

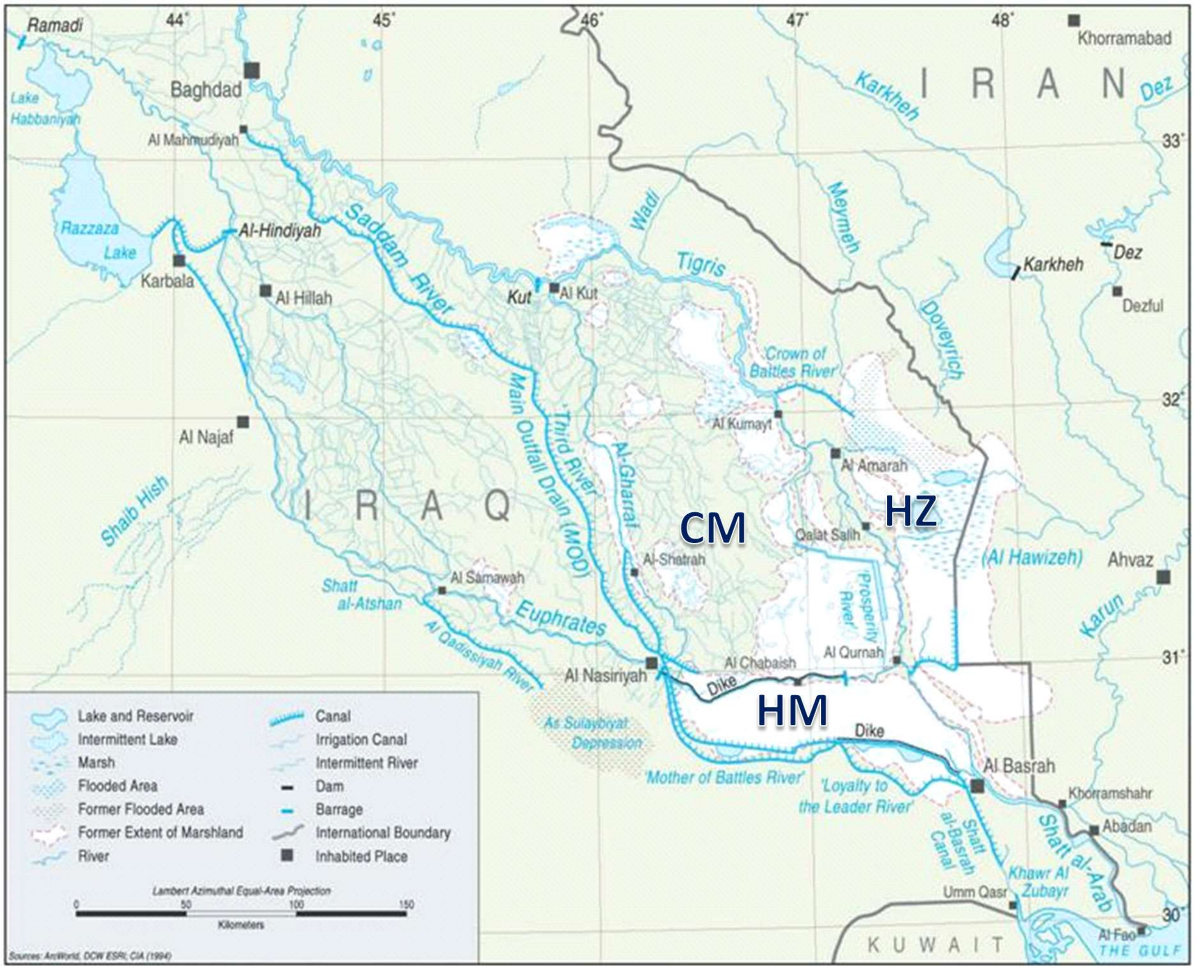


Figure 1–2: Surface water in vicinity of the Mesopotamian marshes. HZ = Al-Hawizeh marsh, CM = Central marsh, HM = Al-Hammar marsh; Source: Partow (2001).

The annual hydrological pattern of the Tigris and the Euphrates Rivers used to have a distinct surge period; a spring peak of water usually between March and May, and a low water period occurring between July and October (Rzoska 1980). The spring freshwater pulse originated mainly from snowmelt in the Turkish and Syrian mountains. As a consequence, the water level and discharge of the rivers increased and filled the marshes with freshwater. In addition, the spring freshwater supply improved water quality and was an important time of the year in the annual biological cycle of the marshes. The spring increase in quantity and quality of water enhanced dissolved oxygen (DO) levels, diluted the salinity and flushed debris such as suspended particulates and organic matter from the previous cycle out of the marsh system. A large amount of suspended material (mainly silt) was carried into the marshes, which enriched the marshes with organic matter and nutrients (Marion and Brient 1998). The effect of the spring pulse gradually faded, giving way to the summer season. In summer, the increase in air temperature that starts in late May increased the evaporation rate and, in turn, the salinity which reached its maximum concentrations, 0.5 part per thousand (ppt), in late August and early September. By the end of the summer season, the production cycle ended leaving the system filled with organic matter and debris. In the fall and into winter, the water level increased slightly due to rainfall in the highlands. Brasington (2001) reported that the annual fluctuation of water column depth (WCD) in the Mesopotamian marshes averaged from 0.5 m to 3.5 m. Figure 1–3 shows the average monthly discharge of the Tigris and Euphrates Rivers from 1931 to 1976 (Polservice and Hydroprojekt 1981). Before desiccation, the fluctuations in salinity and turbidity correspond, in general, to the changes in discharge measured in the Tigris and Euphrates Rivers (Rzoska 1980; Figure 1–3). The spring pulse in water was evident in the discharge data, followed by a gradual increase in flow due to the fall rains after the dry summer period.

Not only were the ecological cycles of the Mesopotamian marshes dependent on the hydrological pattern described above, but the irrigation of agricultural fields and the filling of reservoirs in Iraq were also managed and controlled in coordination with that cycle (IMET 2006). Therefore, alterations to the annual pattern of flow in the Tigris and Euphrates Rivers and their distributaries did not only affect the ecology of the marshes but also irrigation and reservoir management.

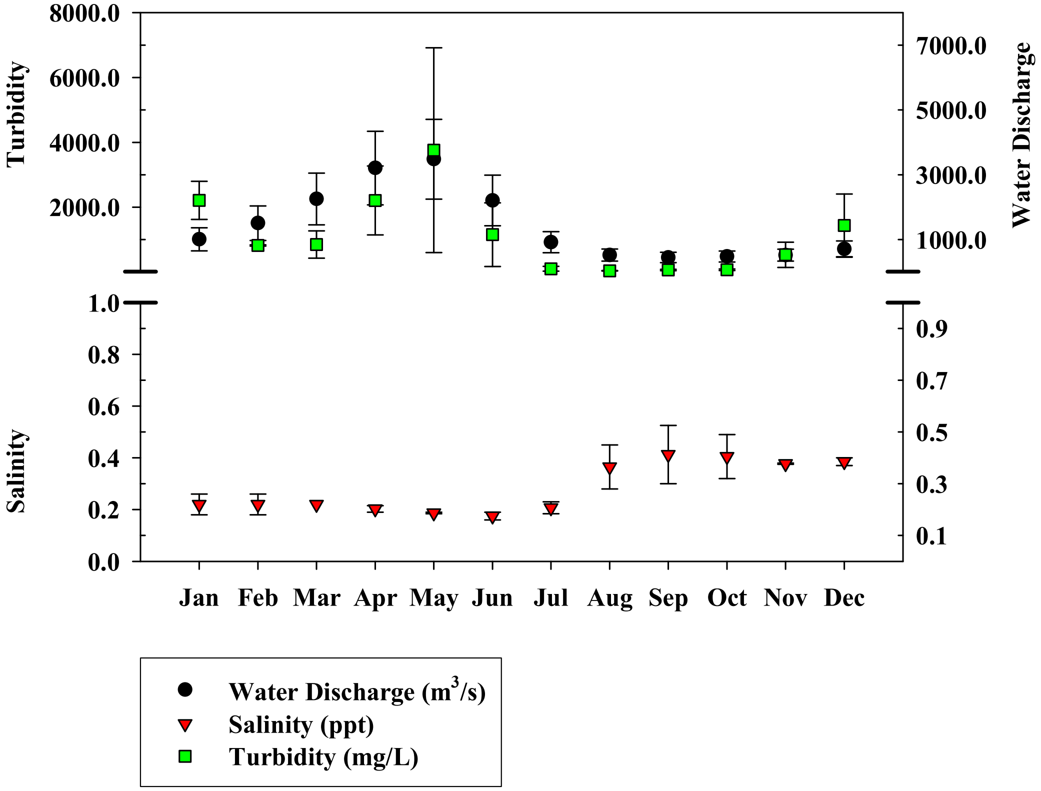


Figure 1–3: Average monthly combined water discharge of the Tigris River measured at the Al-Kut station and the Euphrates River measured at the Al-Nasiriya station (1931 – 1976; source: Polservice and Hydroprojekt (1981). Average salinity (1958 – 1959) and Turbidity (1959); source: (Rzoska 1980).

1.1.3 Anthropogenic Impacts to the Mesopotamian Marshes

Towards the end of the twentieth century, the hydrology of Iraq in general and the ecological characteristics of the Mesopotamian marshes in particular were affected by anthropogenic activities that dramatically changed the hydrological cycle and resulted in the loss of a large portion of the marshes' area and habitats (Partow 2001, IF 2003, IMET 2006).

In the following sections I discuss the major factors that altered the hydrologic regime of the Mesopotamian marshes and led to the destruction of their unique structure.

1.1.3.1 Dam and Barrage Construction

The beneficial goals behind establishing reservoirs and other water-supply infrastructure include controlling the distribution of water and ensuring supply during dry periods. However, if this infrastructure is used improperly, it can have a negative both impact locally and downstream. Turkey and Syria have built or are building several dams and barrages in the upstream portions of the Tigris and the Euphrates Rivers (IMET 2006) reducing the annual water discharge into Iraq. A lack of communication and water sharing agreements between water riparian countries forced Iraq to change its water management scheme for both rivers. Partow (2001) compared the historical water discharge before and after the construction of major dams in Turkey in 1974 and showed the differences in the seasonal fluctuation in the Euphrates River between these periods. There was both a reduction in overall flow during the post-dam period and a loss of the important spring pulse resulting in flows that are now more consistent through the year.

1.1.3.2 Agriculture Impact

For 6000 years the borders of the Mesopotamian marshes have been used as agriculture fields, mainly for rice cultivation (Rzoska 1980, Scott 1995). Since then, the runoff from agricultural lands has influenced the nature of the marshes' water (Mahamed 2008) and sediments (Aqrawi 1994). Several parallel irrigation channels were constructed to catch the excess water from the Tigris and Euphrates Rivers. In the late 1970's, when the water volume of the Tigris and Euphrates Rivers was reduced, the Iraqi government did not reduce the share of water for agricultural irrigation to allow more water to reach the marshes. At the same time, large areas of the marshes were converted into agricultural fields (UNEP 2006). This increase in agricultural land affected the water quality the Tigris and the Euphrates Rivers by adding more pesticides and nutrients, and increased the salinity of the water discharged into the marshes.

1.1.3.3 Petroleum Development

Since 1902, when oil was discovered in Iraq, several major oil fields have been developed within the marshes. The Al-Zubair oilfield, established in 1949, occupies an area of ~100 km^2 in the southeastern section of the Al-Hammar. The Al-Rumaila oilfields established in 1953 west of Basra and southeast of Al-Hammar marsh are the largest production fields and occupy an area of ~300 km^2. In 1954, an extension of this oilfield was established in the northern part of Al-Hammar, occupying an area of ~200 km^2. In the 1980s it expanded 150 km^2 in the north to reach the west part of the Central marshes. West Qurna oil field, located north of Al-Rumaila field, is also one of Iraq's largest oil fields. In Al-Hawizeh, the Majnoon oilfield, established in 1977, occupies an area of ~300 km^2 in the south. As these and other oil fields were developed, more than 10% of the total marshes were drained and destroyed.

1.1.3.4 War Impact

During the Iraq-Iran war, 1980 to 1988, the Mesopotamian marshes were severely damaged. The most dramatic impacts were on the Al-Hawizeh marsh, where the marshes were used as cover, hiding the advancing Iranian army. Most of the eastern part of the Central marsh was dried to meet military needs (Scott 1995). The extensive physical damage due to the digging of trenches and bunkers, and movement of military vehicles, affected the quantity and quality of the water and vegetation cover (Evans 1994, Partow 2001). The use of chemical weapons has resulted in the presence of derelict canisters that pose a threat to the local inhabitants, to scientific personnel, and to wildlife. While the Iraq-Iran war had a direct impact on the marshes, the effect of the first and the second Gulf Wars was indirect through the destruction of sewage treatment plants resulting in untreated waste going downstream to the marshes. By late 1990, the continuous loss of water and the increased evaporation rate made it impossible for the inflowing rivers to deliver sufficient water to keep the marshes inundated. In 1993, the most serious disaster took place; the decision to dry the Mesopotamian marshes.

1.1.3.5 Drainage Program

The drainage of the Mesopotamian marshes began with the construction of major canals and river channels that diverted water past the marshes. The main construction included several canals to take water out of the marshes such as the Main Outfall Drain, the Al-Qadisiyah River, the Mother of Battles River, the Loyalty to the Leader Canal, and the Crown of Battles River (IMET 2006). Changes also included raising the height of the banks of the Euphrates River to prevent the overflow of water into the Central and Al-Hammar marsh, as well as constructing several embankments along the distributaries of the Tigris (IF 2003). The water diversion led to the loss of nearly 33% of the Mesopotamian marshes during the period 1984 – 1992 (Scott 1995) and, by the year 2000, the marshes occupied only 10% of their original size (Partow 2001; Figure 1–4).

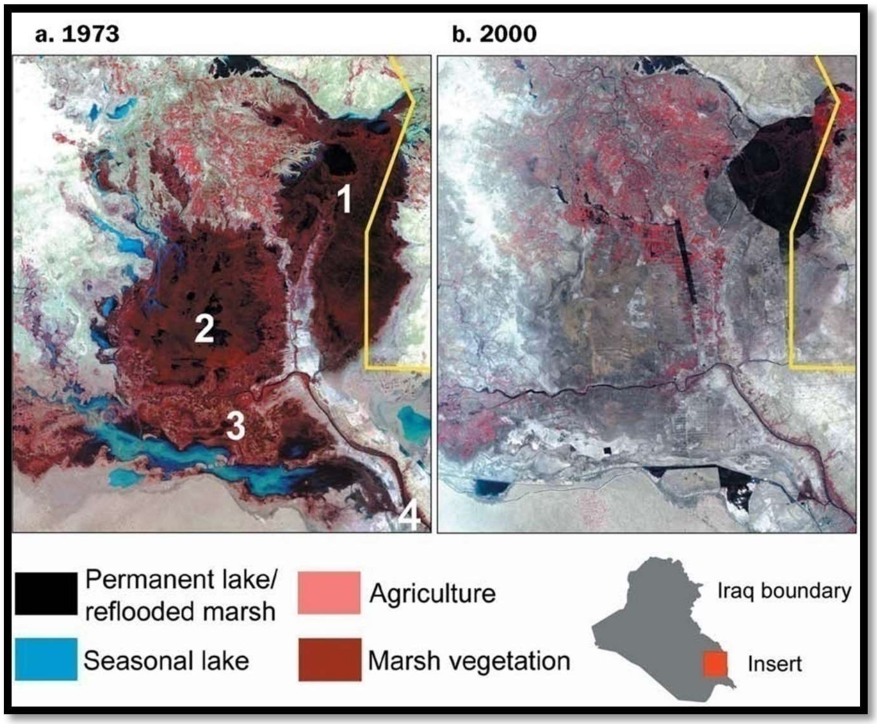


Figure 1–4: Satellite views of the Mesopotamian marshes (1) Al-Hawizeh, (2) Central and (3) Al-Hammar. Source: Richardson et al. (2005).

The desiccation also affected the local people, the Marsh Arabs; the region's human population decreased by approximately half a million to only 50,000 people (Scott 1995, Partow 2001). They were no longer able to earn their living from fishing as they had done previously, or to feed their water buffalo and sell dairy products. In addition, major consequences of the desiccation included loss of the marshes' biodiversity (UNEP 2006). The loss of habitat for migrating birds also caused significant reductions in their populations (Partow 2001).

1.1.3.6 Re-flooding and Recovery of the Marshes

In April 2003, when the government of Iraq changed, the remaining marsh dwellers allowed the water to flow again into the marshes. They started by opening the gates that controlled water flow to the distributaries that fed the marshes and breeching the dikes built across the marshes. The re-flooding encouraged the rebirth of desiccated areas of the marshes and gave hope for recovering the Mesopotamia. The re-flooding processes however, had been ad-hoc and poorly managed without strategic planning, according to an Iraqi Ministry of Water Resources (MoWR) internal report (2011).

Two years after inundation there were hopeful if superficial signs of recovery of the marshes (Warner et al. 2011). The newly re-flooded marshes attracted thousands of people to resettle after they had been displaced for more than 10 years. The new marsh environments reached approximately 55% of their historical size by 2005 (IMET 2006). Just a few months after the re-flooding of the Mesopotamian marshes, many scientists from academia, government, and non-governmental organizations began to study and investigate the new re-flooded system. Richardson et al. (2005) studied the ecological status of the Al-Hammar and the Central marshes after being re-flooded and investigated several water and soil parameters in the newly inundated areas. They concluded that the soil had high organic matter, reflecting high plant productivity.

Al-Shawi (2006) studied physical-chemical parameters of water samples from Al-Hammar marsh. He found that the concentrations of nitrate (NO_3^-), nitrite (NO_2^-), and soluble reactive phosphate (SRP) ranged between 9.7 and 35.5 µg/L, 0.27 and 0.41 µg/L, 0.16 and 15.87 µg/L, respectively. He concluded that the nutrients concentrations, although low, had increased during the last twenty years due to the accumulation of the organic matter during the desiccation period. Most of the studies carried out after the inundation of the Mesopotamian marshes were reviewed by Warner et al. (2011). In general, all of the marshes waters have alkaline pH, and most are well oxygenated ($DO \geq 5$ mg/L); however, in some areas of high organic matter production oxygen depletion was observed ($DO < 0.2$). Low concentrations of chlorophyll *a* (Chl $a \leq 1$ µg/L) indicate oligotrophic conditions.

Phytoplankton were studied in 2004 in the Central marsh by the New Eden Team (IF 2008). Just after re-flooding, New Eden Team identified a total of 130 species that belong to six phytoplankton phyla among the Mesopotamian marshes including: Bacillariophyta, Chlorophyta, Cyanobacteria, Euglenozoa, Dinophyta, and Cryptophyta in Abu Zarag marsh, Central marshes. They indicated that the most dominant genera present were the cyanobacterial genus *Oscillatoria,* and the diatom genera, *Nitzschia* and *Navicula*. The New Eden Team also noted that the abundance of phytoplankton ranged from 836 cells/ml to 35,384 cells/ml and observed that the toxic dinoflagellate, *Peridinium cinctum* (O.F.Müller) Ehrenberg, was present (154 cells/ml) during their study period (IF 2008). The Canadian – Iraq Marshland Initiative project reported during the INTECOL/ESA meeting in Montreal, Canada, (August 2005) that 85 species of phytoplankton were identified at Al-Hawizeh marsh, 89 species at Central marsh and 64 species at Al-Hammar marsh. Nature Iraq reported in their Habitat Mapping and Monitoring Project for Al-Hammar marshes a total of 54 phytoplankton species and total abundance of 502,800 cells/ml (Abdulhassan et al. 2009). They indicated that phylum Bacillariophyta (334,700 cells/ml) was dominant among the phyla followed by Chlorophyta (107,600 cells/ml).

Macrophyta were investigated in the newly re-flooded marshes. The Canadian – Iraq Marshland Initiative project reported 19 species of macrophytes representing 11 families. Only one of them, *Hydrilla* *verticillata*, was considered to be an exotic. The most frequent species was *Ceratophyllum demersum* (82.5%). Emergent plant cover in Al-Hammar marsh was dominated by *Schoenoplectus litoralis* (49.46%), *Typha domingensis* (36%) and *Phragmites australis* (22.5%), while *Ceratophyllum demersum*, *Najas marina* and *Potamogeton pectinatus* constituted the highest cover for submerged plants.

1.2 Assessment of the Mesopotamian Marshes

Assessing the water quality and the biological functions of Mesopotamian marshes are necessary to determine if the re-flooding methods that have been used are achieving recovery. Generally, it is challenging to institute recovery programs for heavily damaged environments, like the Mesopotamian marshes. The challenges include that these wetlands have been affected by several anthropogenic stressors like desiccation and that the water supply is diminishing and changing in its seasonal timing (IMET 2006, UNEP 2011, Warner et al. 2011).

It is important to identify the major sources of damage to design a recovery plan and suitable recovery methods. The hydrological challenges have resulted in disputes between Iraqi hydrologists and ecological scientists. Hydrologists insist that the re-flooding itself should be enough to provide a suitable condition for the marshes recovery. No doubt water is one of the most important components of a wetland (Mitsch and Gosselink 2007), but from an ecological perspective, the supply of water to the marshes needs to be sufficient in quality, as well as quantity, in order for the marshes to maintain their ecological functions.

1.2.1 Ecological Assessment

The term ecological assessment (EA), in the broadest sense, involves the monitoring of an ecosystem to identify both the current state and changing conditions due to natural drivers or anthropogenic activities (Faber-Langendoen et al. 2006). Generally, EA uses abiotic and biotic indicators that have the ability to reflect the fundamental and functional components of ecosystems (Latour and Groen 1994, EPA 2002) to report on the state of the environment and to be integrated into comprehensive indices (Faber-Langendoen et al. 2006). The US-Environmental Protection Agency (US-EPA) uses two levels of assessment:

- Level 1: A screening process that characterizes the water quality in the studied areas and identifies potential sources of impacts. At this level it is also possible to identify which water bodies are at risk.

- Level 2: Conducted for areas that have been identified as impaired by the first assessment level (Level 1). At this level, researchers attempt a detailed examination of impact sources and a complete description of water quality problems.

The applications of EA are normally guided by laws and criteria. The complexity of applying an EA is mainly related to regional and temporal variation in the vulnerability of ecosystems, and to limitations in our understanding of the overall function and health of ecosystems (Kelly and Harwell 1990). Ecological indicators should be able to reflect the current condition of the ecosystem, provide an early warning to changes, and diagnose the causes of changes and problems (EPA 2003). Usually, abiotic indicators such as chemical and physical characteristics are used to detect pollutants and disturbance, while the biotic indicators are mostly used to differentiate between healthy ecosystems and those at risk (Zonnevels 1983). Recent studies of wetlands have used various methods to identify water quality problems, indicate the possible sources of the problems, and suggest changes in management practices or recovery possibilities.

For aquatic systems, the term wetland ecological assessment (WEA) generally refers to the evaluation of water quality (chemical and physical characteristics) and biological (flora and fauna) status of a wetland. Lemly et al. (2007) provided a theoretical framework that emphasizes both human values and wetland ecosystem functions in problem formulation, risk characterization and risk management (Figure 1–5). They summarize some guidelines for WEA in wetlands and explain the importance of understanding wetlands function as the heart of the risk assessment and management processes.

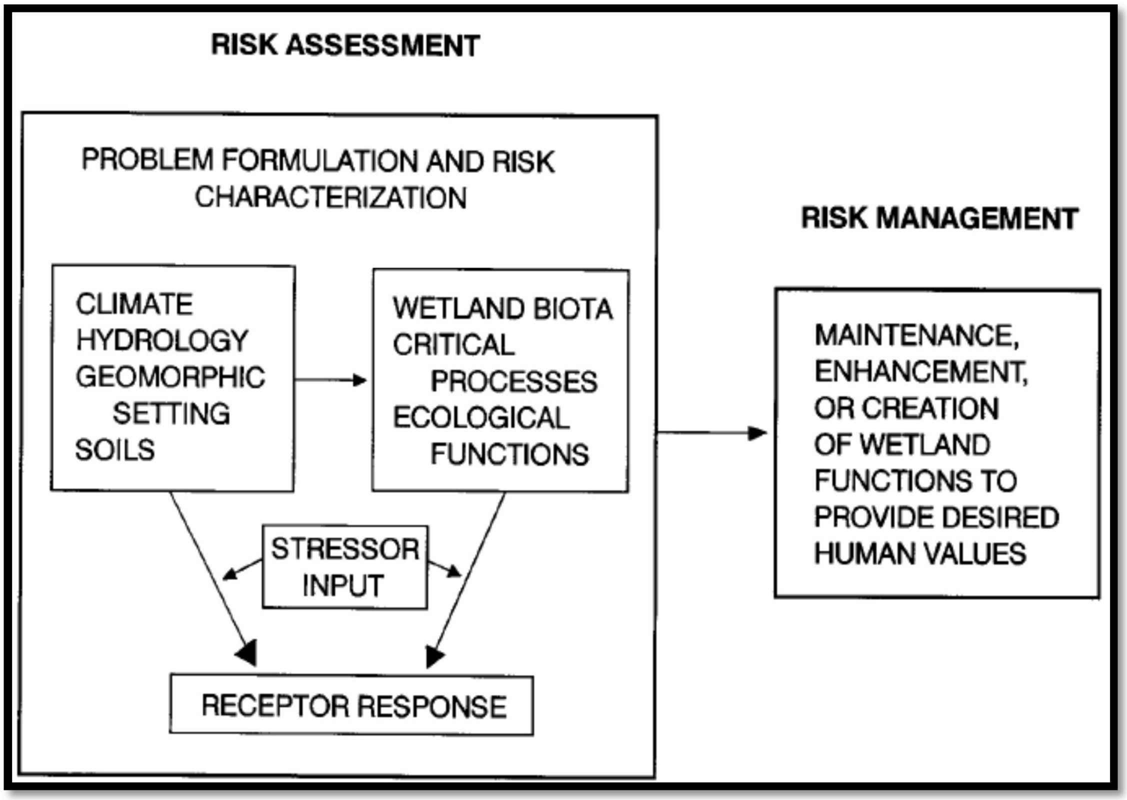


Figure 1–5: Theoretical framework for WEA. Source: Lemly et al.(2007).

WEA methods are generally based on several fundamental aspects that identify and support planning and managing wetland ecosystems and species (EPA 2008). The main fundamental steps of WEA are discussed in the subsequent sections.

1.2.2 Critical Questions and Essential Indicators

The principal aim in the assessment of an affected ecosystem is to fully understand that system before it is severely affected (Haines-Young and Potschin 2009). This can likely be achieved if previous research provides historical data for the ecosystem of interest and if suitable control sites exist (Falk 2006). In other words, data from pre-damage conditions can be extremely valuable in determining the degree of system deterioration and the feasibility of maintaining certain beneficial uses when historical ecological data for the damaged site(s) are not available (Falk, 2006; Clewell & Aronson, 2007; Doyle & Droe, 2008). Reference systems that have similar ecological characteristics to the damaged system can be used also to represent natural conditions prior to significant disturbance (Falk 2006, Clewell and Aronson 2007). If available reference sites can provide insights into pre-damage conditions of the environment of concern that help in the development of a complete assessment (Lemly and Richardson 2007). In the case of the Mesopotamian marshes, historical information for most of the ecological parameters are rare. Desiccation damaged over 90% of the marshes so the 10% of the marshes that remained wet can be useful for comparison. However, these areas still were affected by the impacts of water shortage and war.

Recently, researchers are building their assessment strategies by constructing several critical questions and treating them as hypotheses in order to solve problems (Richardson et al. 2005, Clewell and Aronson 2007, Doyle and Droe 2008). These questions could be simple and answerable through a short monitoring program or even a snapshot survey, or they could be complex questions such that researchers might have to follow several pathways that require different methods and analyses to accomplish the final result (Clewell and Aronson 2007). Choosing the right indicator or indicators is very important for obtaining a comprehensive EA, and requires a thorough understanding of the history of the system to be studied (CCME 2003).

1.2.3 Water Quality Standards

Water quality standards are laws or regulations designed to protect ecosystems, public health and welfare (EPA 1986, WHO 2004, Lemly and Richardson 2007). For aquatic systems, water quality standards are developed to maintain or restore the chemical, physical, and biological integrity of waters and to achieve water quality that protects aquatic life (EPA 2008). The US-EPA includes three main elements for water quality standards: 1) the beneficial uses of the water body; 2) the water quality criteria required to protect those uses of that water body; and 3) an anti-degradation policy (Adriaanse 1993). The water quality criteria or guidelines can be described either as quantitative limits or as qualitative descriptions (WHO 2004). Practically, criteria are set at levels that protect the most sensitive uses, such as health of humans drinking that water, or health of aquatic life. The responsibility of the anti-degradation policy is to ensure that water quality is conserved, maintained, and protected (EPA 2008).

1.2.4 Ecological Indicators

Physical-chemical indicators and biological indicators have been used to identify critical criteria for aquatic systems (Table 1–1). Recently, many different types of water quality parameters have been used to reflect a variety of chemical and physical aspects of ecosystems (WHO 2006).

Table 1–1: Water indicators used for wetland ecological assessment.

Indicator s	Criteria	Impact	Reference
Hydrology	**Total Suspended Solids Load**	Indirectly impacts aquatic biota by reducing habitat, eliminating sensitive food organisms, reducing sunlight penetration to submerged aquatic plants and algae thereby impairing photosynthesis, and transporting nutrients and toxic compounds such as pesticides.	Marion and Brient (1998), Lemly and Richardson (2007), Mitsch and Gosselink (2007)
Biogeochemistry	**Nutrients**	Eutrophication can affect aquatic populations and communities and in some cases increase the productivity of algae and macrophytes leading to increased decomposition of organic matter and DO depletion.	Mitsch and Gosselink (2007)
	Heavy metals	Have toxic effects on microorganisms, fish, wildlife and humans, directly or through the food chain.	Lemly and Richardson (2007)
Physical-chemical	**Water temperature**	Below or above individual thresholds stresses aquatic populations and may lead to changes in the aquatic community assemblages and/or productivity. Warmer temperatures may increase organic decomposition rate and disease transmission.	Mitsch and Gosselink (2007)
	Salinity	Influences the distribution and abundance of organisms.	Nielsen et al. (2003)
	pH	Affects the behaviour of nutrients and metals, and influences the toxicity of pollutants because of its effects on ionization and bioavailability.	Witters (1998)
	DO	Necessary for the maintenance of aerobic life and aquatic species diversity; modifies the effects of toxicants and fate of nutrients.	Kelly and Harwell (1990), Mitsch and Gosselink (2007)

Biological conditions, both community composition and organism health, are widely used as indicators of water quality (EPA 2002). Monitoring biological conditions can provide a comprehensive assessment of the scope of change to an impacted ecosystem (Lemly and Richardson 2007) and can also be diagnostic of the cause (Nielsen et al. 2003, Blinn et al. 2004). It can provide useful information on habitat alteration, the cumulative effects of pollutants and other stressors, and the loss of ecosystem services.

Phytoplankton have been commonly used in EA methods (EPA 2002) as they are important contributors to primary production in many aquatic systems, including wetlands (Mitsch and Gosselink 2007). Phytoplankton communities have significant impacts on processes such as organic matter production, nutrient uptake, nitrogen-fixation, oxygen dynamics and light attenuation (D'Autilia et al. 2004, Lek et al. 2005) and play an essential part in the food web (Wetzel 2001). In addition, algae blooms can cause health issues as they can produce natural toxins that cause negative impacts such as poisoning, allergies, mechanical damage to other organisms and in some circumstances their toxins can cause death (Harold 2014). The most common algal groups that are widely used as bio-indicators will be discussed in detail in Chapter 4.

1.3 Pre desiccation status of the Mesopotamian marshes

It is important to review the pre-desiccation condition of water quality and phytoplankton in assessing recovery of the wetlands. Before the desiccation of the Iraqi marshes, there were several studies of the physical-chemical parameters of the Al-Hammar and Central marshes (Al-Sahaf 1975, Antoine 1977, Maulood et al. 1979, Pankow et al. 1979, Al-Saadi et al. 1981, Maulood et al. 1981, Al-Mousawi and Whitton 1983, Al-Zubaidi 1985, Al-Lami 1986, Kassim 1986). The pre-desiccation studies indicated acceptable water quality, especially during the 1970s period (Table 1–2).

Table 1–2: Physical and Chemical Characteristics of the Mesopotamian waters pre-desiccation (Hussain 1994).

		1970s			**1980s**		
Water Quality Parameters	**Units**	**Average**	**Minimum**	**Maximum**	**Average**	**Minimum**	**Maximum**
Water Column Depth	m	2.6	2.0	3.5	0.6	0.3	1.0
Transparency	m	1.7	0.2	3.5	0.7	0.3	1.2
pH		7.7	7.1	8.2	8.1	7.4	9.2
Dissolved Oxygen	mg/L	4.9	4.5	5.3	7.0	1.7	12.0
Total Suspended Solids	mg/L	0.0	0.0	0.0	-		
Salinity	pus	0.4	0.2	0.7	3.3	0.6	21.5
Alkalinity	mg/L	923.5	329.4	1805.6	144.4	53.0	355.0
Calcium	mg/L	-			162.5	11.0	311.0
Magnesium	mg/L	-			246.6	32.0	3265.0
Sulphate	mg/L	-			39		
Chloride	mg/L	-			240		
Nitrate	µg/L	142.6	36.0	300.0	1.5	0.0	9.2
Silicate	µg/L	746.7	720.0	800.0	97.4	10.0	306.7
Phosphate	µg/L	15.2	10.0	26.0	0.4	0.1	1.9

Pre-desiccation studies of phytoplankton were rare and covered a limited area of the marshes (Al-Kaisi 1976, Maulood et al. 1979, Pankow et al. 1979, Al-Saadi et al. 1981, Maulood et al. 1981, Al-Saboonchi et al. 1982, Kassim 1986). Talib (2009) summarized the significant studies that have been conducted during the 1970s and 1980s (Table 1–3).

Table 1–3: Total species count of the identified phytoplankton phyla in the Mesopotamian marshes pre-desiccation (Shawi 2007, Talib 2009).

Bacillariophyta	**Chlorophyta**	**Cyanophyta**	**Miozoa**	**Euglenozoa**	**Cryptophyta**	**Ochrophyta**	**Study Area**	**Study period**
89	20	17	2	2	1		East Al-Hammar	1975
72	28	26					Central Marshes	1979
	28	31	1	2	1	1	Central Marshes	1981
	38	61			1		Central Marshes	1982
	38	19					Al-Hammar	1982
	14						Al-Hammar	1983
156	26	10	1	2		1	Al-Hammar	1985
72	28	26		2	1		East Al-Hammar	1986
79	24	12	2	2		1	Al-Hammar	1988
78	19	11	3	3	2		Al-Hammar	1988

The most common recorded species of phytoplankton identified pre desiccation period are listed in Table 1–4.

Table 1–4: The most common phytoplankton species recorded pre-desiccation of the Mesopotamian marshes (Pankow, Al-Saadi, et al. 1979, Shawi 2007).

Phylum	Class	Species
Cyanobacteria	**Cyanophyceae**	*Arthrospira platensis* Gomont
		Dolichospermum sigmoideum (Nygaard) Wacklin, L.Hoffmann & Komárek
		Gloeocapsa turgida f. maxima (Nygaard) Hollerbach
		Oscillatoria tenuis C.Agardh ex Gomont
Chlorophyta	**Trebouxiophyceae**	*Actinastrum hantzschii* Lagerheim
		Micractinium pusillum Fresenius
	Ulvophyceae	*Cladophora* sp. Kützing
	Chlorophyceae	*Oedogonium undulatum* A.Braun ex Hirn
		Chlamydomonas sp. Ehrenberg
		Dimorphococcus lunatus A.Braun
		Monactinus simplex (Meyen) Corda
		Pediastrum simplex Meyen
		Pediastrum duplex Meyen
		Scenedesmus bijuga (Turpin) Lagerheim
Charophyta	**Zygnematophyceae**	*Mougeotia* sp. C.Agardh
Euglenozoa	**Euglenophyceae**	*Lepocinclis acus* (O.F.Müller) Marin & Melkonian
Ochrophyta	**Chrysophyceae**	*Dinobryon* sp. Ehrenberg
Bacillarophyta	**Mediophyceae**	*Chaetoceros* sp. Ehrenberg
		Terpsinoë americana (Bailey) Grunow
		Terpsinoë musica Ehrenberg
	Coscinodiscophyceae	*Melosira* sp. C.Agardh
	Bacillarophyce	*Achnanthes crenulata* Grunow
		Amphiprora sp. C.G.Ehrenberg
		Bacillaria paxillifera (O.F.Müller) T.Marsson
		Gomphonema sp. Ehrenberg
		Gyrosigma sp. Hassall
		Navicula sp. Bory de Saint-Vincent
		Nitzschia sp. Hassall
		Rhoicosphenia abbreviata (C.Agardh) Lange-Bertalot
	Fragilariophyceae	*Diatoma vulgaris* Bory de Saint-Vincent
		Synedra ulna (Nitzsch) Ehrenberg

Most of the pre-desiccation phytoplankton studies reported only the total count of species and taxonomy (Hussain 1994). Al-Kaisi (1976) found that Cyanobacteria were dominant among the other phytoplankton groups (86%), whereas Al-Zubaidi (1985), Al-Lami (1986), and Hassan (1988) found the Bacillarophyta were dominant among the other phytoplankton classes such as Chlorophyta and Cyanobacteria in the marshes. Maulood et al. (1981) in their study found that cyanobacterial genera including *Aphanocapsa* sp., *Chroococcus* sp. *Phanothece* sp. were commonly observed in the Mesopotamian marshes, especially during fall, while *Dolichospermum* sp., *Gomphosphaeria* sp., and *Microcystis* sp. were infrequent.

Maulood et al, (1979) reported some brackish and marine species including *Cocconeis placentula* Ehrenberg, *Diploneis elliptica* (Kützing) Cleve, *Nitzschia filiformis* (W.Smith) Hustedt, and *Synedra ulna* (Nitzsch) Ehrenberg in the Al-Hammar marshes and in the Shatt Al-Arab River. Al-Zubaidy (1985) and Nur Al Islam (1982) observed that some brackish and marine phytoplankton genera such as *Terpsinoë* and *Synedra* are widely distributed among the Al-Qurna marshes, southeast Al-Hammar marsh, possibly associated with higher salinity there.

1.4 The ecological assessment of the Mesopotamian marshes status after re-flooding

The ecological assessment of the Mesopotamian marshes status after re-flooding is based on changes in the water quality and biological condition of the marshes. In Chapter 2 I address the issue of salinization and the main sources of increasing salinity. In Chapter 3 I choose some physical and chemical parameters to assess the water quality and in Chapter 4 I use phytoplankton assemblages to assess the biological status of the Mesopotamian marshes after re-flooding.

1.5 Thesis Objectives

The main goal of my thesis is to define the current hydrological and ecological status of the Mesopotamian marshes after re-flooding. My study is based on information collected through several monitoring surveys in which I was involved. These surveys are summarized in Table A1 in Appendix 1. Also my thesis research attempts to understand and identify the factors that are limiting the recovery of the re-flooded Mesopotamian marshes to their pre-desiccation historical condition. Specifically, I will address the following questions:

- How has the hydrology of the Tigris and Euphrates Rivers changed?
- How has the salinity of the marshes changed in the last three decades? What are the main causes leading to increased salinity of the marshes after re-flooding?
- What is the overall water quality status of the Mesopotamian marshes after re-flooding compared to their historical status?
- What are the major parameters affecting the water quality of the Mesopotamia marshes after re-flooding?
- Are there differences in species composition and abundance in phytoplankton communities among the selected re-flooded marshes in Al-Hawizeh marsh?
- What environmental parameters might help to explain any observed differences in composition and abundance of phytoplankton communities?

Chapter 2

The Hydrological Challenges & the Salinization of the Re-flooded Mesopotamian Marshes

2.1 Introduction

2.1.1 Hydrological challenges

As outlined in Section1.1.3, the hydrological conditions in the Mesopotamian marshes are related directly to the hydrology of the Tigris and the Euphrates Rivers (Rzoska 1980). Water use upstream is a major problem affecting the water quantity and quality of the Tigris and Euphrates and thus the marshes (Partow 2001, Warner et al. 2011). Since the late 1980s, the reduction in flow of the two rivers has led to a reduction in water supply to the marshes and also signalled early salinization problems (Al-Manssory 2008).

2.1.1.1 Impact of Bad Water Management

The Iraqi government has managed to control water shortages somewhat by using reservoirs and water regulators, and the drying of the marshes in the early 1990s resulted in part from use of water upstream for more urgent purposes such as drinking and irrigation (IF 2003, IMET 2006). Closing of the major water inputs and building embankments during the drainage process altered the water supply to the marshes and affected the hydrological and ecological structure of the marshes (IF 2003).

Water shortage became an important obstruction to the recovery process of the Mesopotamian marshes (Al-Manssory 2008, Warner et al. 2011). After inundation in 2003 and during the next three years, 30% of the marshes were re-flooded and subsequently became a focal point of international research examining the ability of the marshes to recover. In 2008, the Iraqi MoWR reported that only 43% of the total marsh area had been restored. The remaining 57% of the area remains dry due to agricultural and oilfield related activities. Although the total size of the re-flooded marshes has increased after inundation, especially during 2006 – 2007, the situation is not sustainable as water resources will continue to be challenged (Al-Manssory 2008, Warner et al. 2011). The great water pulse with re-flooding encouraged the rebirth of the aquatic ecosystem and gave hope for restoring the ecological integrity of the area (Mahamed 2008, Douabul et al. 2012, AlMaarofi et al. 2013). Although the re-flooded marshes are showing different levels of recovery (IMET 2006, Mahamed 2008), the flooding process is still poorly managed and some of the flooded marshes continue to receive or have poor quality water (Mahamed 2008). The Iraqi MoWR did develop a Water Management Plan (WMP) for the marshes recovery based on theoretical assumptions that never been achieved (IMET 2006). The WMP assumes that; 1) Iraq will receive at least 200 m^3/sec water from turkey, 2) Al-Hawizeh marsh will keep receiving additional water from Iran, and 3) the water level of Shatt Al-Arab will stay constant with the extra input from Iran. Also, the WMP did not take under consideration the fact of decreasing water supply and natural threats like global warming, and did not include the amount of water required for oil production and development. The failure of the WMP to address the amount of water required to sustain the marshes led the MoWR to adopt several alternative ways to obtain the minimum requirement of water for the marshes (MoWR 2011). Most of these alternatives either failed or caused different ecological problems. For example, one of the main alternatives for water supply to the marshes is the Main Outlet Drain (MOD), which is totally agriculture water discharge. However, this source of water as a solution emphasizes the problem of salinization because it contains high concentrations of salts and is otherwise of poor quality.

2.1.1.2 Impact of Desiccation

Anthropogenic desiccation has resulted from agriculture, petroleum development and military activities. After re-flooding the Mesopotamian marshes in April, 2003, their average salinity gradually increased (Richardson and Hussain 2006) and salinization has become a major problem and a threat to aquatic life (Hart et al. 2003, Nielsen et al. 2003, James et al. 2009). Fitzpatrick (2004) describes how the desiccation process resulted in water quality changes and the accumulation of salt on the surface of the dried sediment due to evaporation (Figure 2–1). The first and second panels in Figure 2–1 display the historical state of the marshes as a relatively undisturbed aquatic system prior to 1980. The marshes then went through processes of drainage in the 1980s and 1990s.

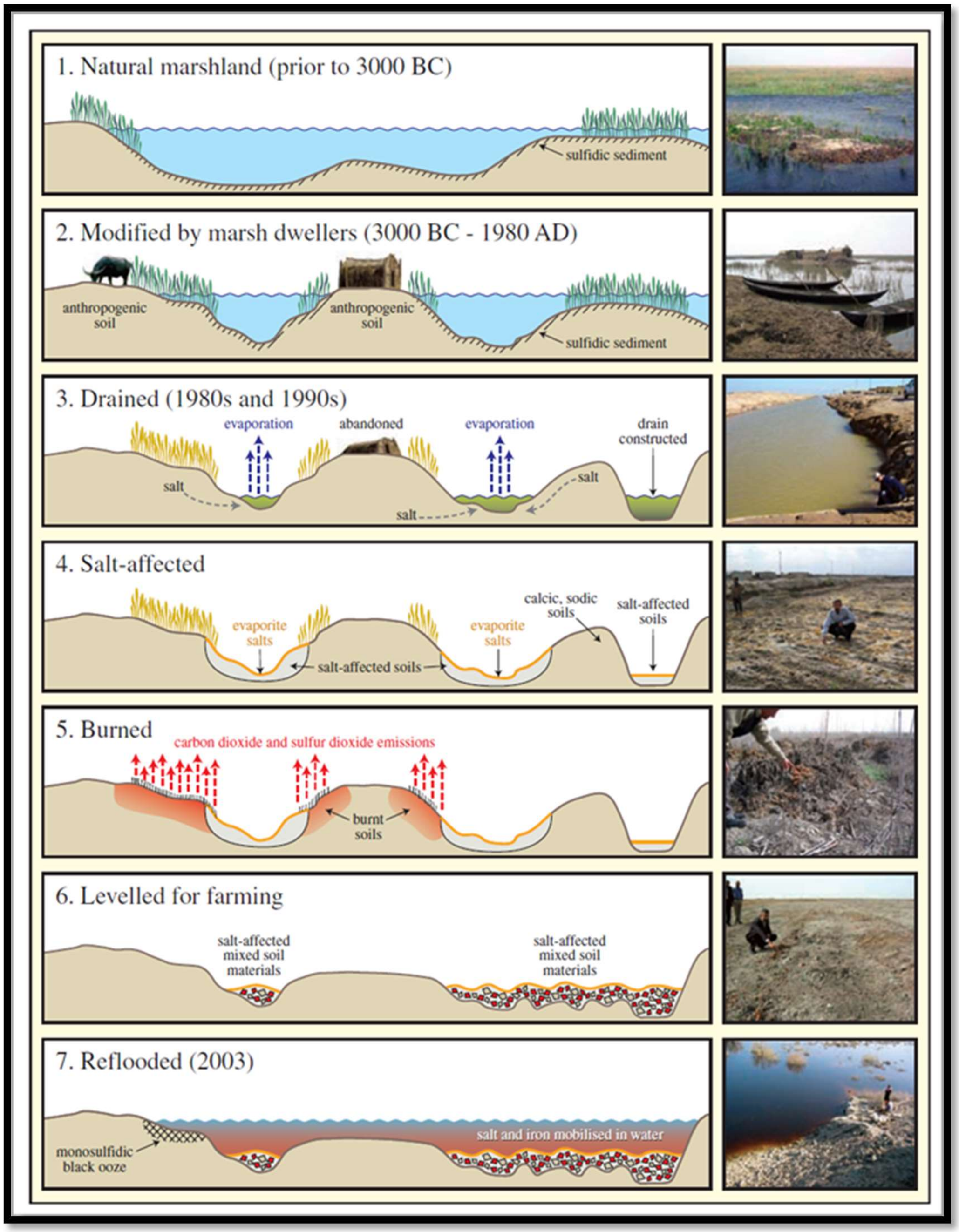


Figure 2–1: Anthropogenic desiccation of the Mesopotamian marshes Source: Fitzpatrick (2004).

2.1.2 Recovery Potential

Water quantity and quality have become the focus of much of the research on the ecological integrity of the re-flooded marshes and on their potential to recover (Richardson and Hussain 2006). Currently, the recovery of the marshes has been seriously undermined by water shortages, uncoordinated water regulation of the Tigris and Euphrates Rivers, and a lack of water sharing agreements among riparian countries, especially Turkey (UNEP 2011). In addition, since the re-flooding, the threat of salinization still exists, casting doubt on whether the ecological recovery of the re-flooded marshes will be successful (Richardson et al. 2005, Richardson and Hussain 2006, Al-Manssory 2008, AlMaarofi et al. 2013).

The first step in investigating the capacity of a wetland in recovery is to compare its status after damage with pre-damage conditions. Historical data on the Tigris and the Euphrates Rivers were summarized in Rzoska (1980). The water quality of the two rivers differs due to the geology through which they pass. The upper basins of the Tigris and Euphrates Rivers consist mainly of limestone ($CaCO_3$) and gypsum ($CaSO_4$), respectively (Rzoska 1980). The salinity of the rivers increases gradually toward the lower basin, particularly due to sodium (Na^+) and chloride (Cl^-) ions (Rzoska 1980). The historical record illustrates that the average salinity in both rivers was inversely related to water discharge, and ranged from 0.2 g/L in the high discharge of winter and spring (January – April) to 0.5 g/L during the low discharge of summer (June – August) during 1958 – 1959 (Rzoska 1980). Historically (pre-1970) the Mesopotamian marshes were considered to be freshwater systems with salinity typically below 1 g/L (Maulood et al. 1979). Studies of the Mesopotamian marshes during the 1980s indicate that their salinity generally increased and ranged from 0.2 to 1.3 g/L (Hussain 1994).

2.1.3 Salinity and Salinization

Salinity is a simple concept, but technically its measurement can be challenging. Simply, salinity is a measure of dissolved salt concentration, including the cations Na^+, K^+, Ca^{2+} and Mg^{2+} and the anions Cl^-, SO_4^{2-} and HCO_3^- in water or soil (Wetzel 2001). Dissolved matter is defined as that which can pass through a very fine filter (usually 0.2 µm). In seawater, 85.7% the dissolved salt consists of Na^+ and Cl^- but in fresh water Ca_2^+ and HCO_3^- generally predominate.

The United States Geological Survey classifies saline water in three salinity categories: slightly saline water, in which salt concentration in water is around 0.1 to 1.0 g/L; moderately saline water 1 to 10 g/L; and highly saline water 10 to 35 g/L. Ocean water has a salinity of roughly 35 g/L. Lower values can be reported near coasts where rivers enter (Rzoska 1980, Anati 1999). The Dead Sea has a salinity of more than 200 g/L.

Salinity can be estimated by measuring how well electricity travels through the water (i.e., its "conductivity") but is generally expressed in the form of a mass fraction (i.e., the mass of the dissolved material in a unit mass of solution). In oceanography, salinity is generally given in practical salinity units (psu), which is a unit based on the conductivity properties of sea water. It is equivalent to ppt or to g/L. The standard unit for electrical conductivity (EC) of water is micro-Siemens per centimetre (µS/cm) at 25 °C (UNESCO 1985). The practical salinity scale defines salinity in terms of the conductivity ratio of a sample to that of a solution of 32.4356 g of KCl at 15 °C in a 1 kg solution (Lewis 1980). For example, a sample of seawater at 15°C with conductivity equal to this KCl solution has a salinity of exactly 35 psu. Rivers or lakes water with a salinity of around 0.7 g/L will typically have a specific conductivity at 25 °C of between 80 and 130 µS/cm. Conductivity usually changes by about 2% per °C, so the measured conductivity at 5 °C might only be in the range of 50 – 80 µS/cm. EC is measured by passing an electric current between two electrodes in a water sample and measuring how readily current flows (i.e., is conducted) between the plates (APHA 2005). In the field, EC can be measured by different kinds of portable probes.

Another common method for determining salinity is by measuring the total dissolved solids (TDS). TDS is measured by evaporating a known volume of filtered water to dryness, then weighing the solid residue remaining (APHA 2005). TDS is usually recorded in mg/L or ppm but the latter is not a favoured unit. Density measurements are also used to estimate salinity, particularly in highly saline lakes. Sometimes density at a specific temperature is specified (Anati 1999). An empirical salinity/density relationship may be developed for a particular body of water and used to estimate the salinity of samples.

The process of increasing salinity above the natural value of any environment is referred to as salinization (Nielsen et al. 2003). Lakes and wetlands can be naturally saline with salinities over 1 g/L, such as salt marshes in coastal Georgia, U.S.A., Great Salt Lake in Utah, U.S.A., and the tidal marsh along the Edisto River in South Carolina, U.S.A. (SalCon 1997). The sources that contribute salt to an environment can be separated into two categories: natural associated salinity (NAS) or primary salinity and anthropogenic associated salinity (AAS) or secondary salinity (Figure 2–2). NAS is often associated with saline groundwater, evaporation in closed basins over a long period of time, or invasion of marine water (Bailey and James 2000). AAS is an increase in salinity due to anthropogenic actions such as pollution and changing land use (e.g., land clearing and irrigation).

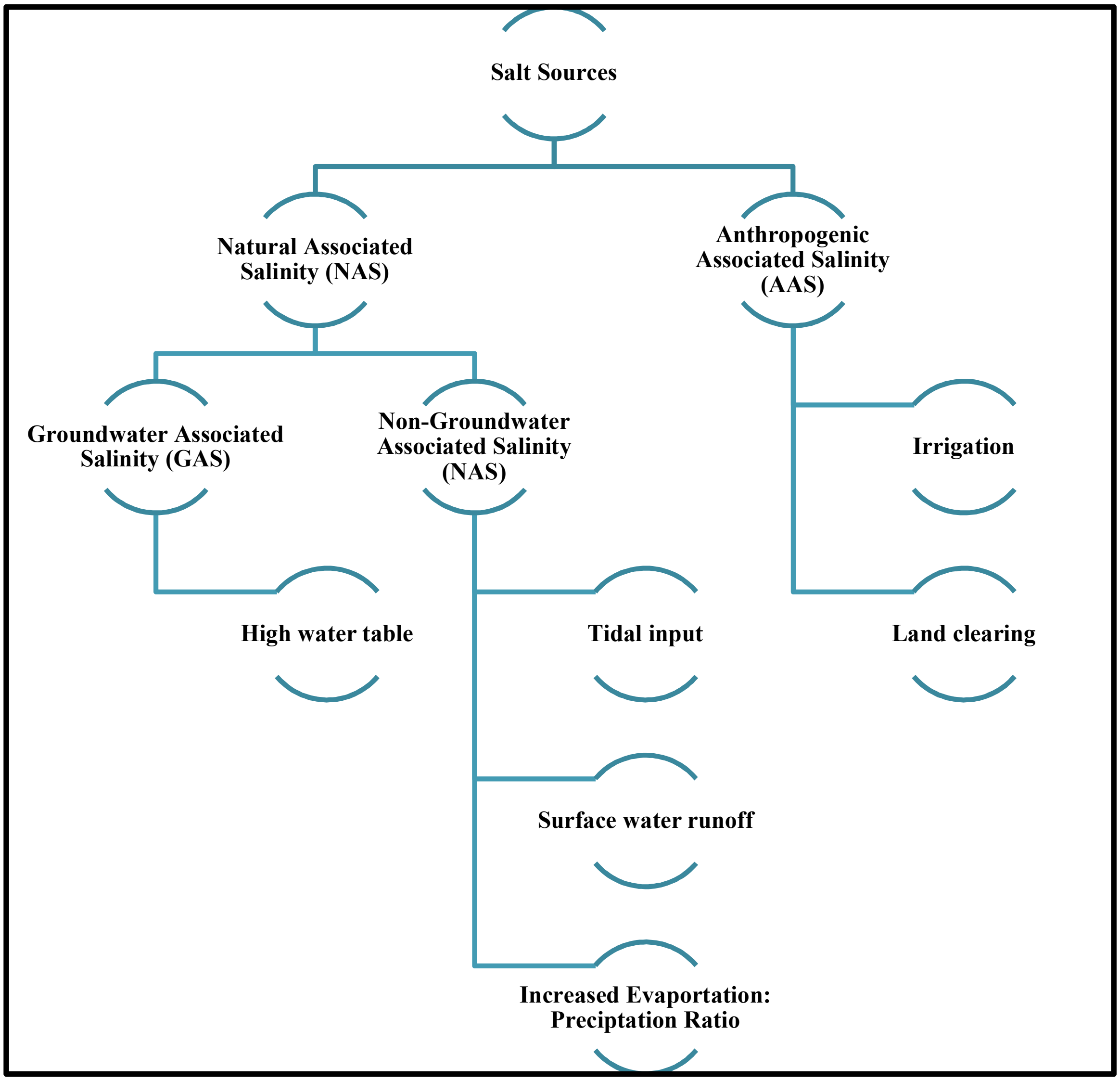


Figure 2–2: Salt resources to aquatic ecosystems Source: http://www.nrm.qld.gov.au/salinity.

2.1.4 The Impact of Salinization on Aquatic Systems

Salinization is a concern around the world. The consequences of salinization are often severe, in part because they are coupled with significant changes in the hydrology and ecology of the catchment (SalCon 1997, Nielsen et al. 2003). Increasing salinity alters the structure and function of freshwater ecosystems (Bailey and James 2000, Blinn et al. 2004). Clearly, salts dissolved in freshwater systems play an important role in chemical processes and the metabolic functions of organisms (SalCon 1997).

Freshwater biota will be significantly affected if the salinity exceeds 1.0 g/L (Hart et al. 1991, Nielsen et al. 2003). Salinity tolerance varies among organisms, and increasing salinity may cause species succession leading to a decline in biodiversity and dominance of salt-resistant organisms, potentially altering ecosystem structure and function (Nielsen et al. 2003). Fish and other marine animals (crabs, shrimps, and clams) that inhabit brackish water can take advantage of increasing salinity, and invade formerly freshwater habitats to compete with native freshwater fish (Gutierre et al. 2013). In the Mesopotamian marshes, the population of *Barbus esocinus* Heckel (a large freshwater cyprinid) was reduced after re-flooding due to the increase in salinity (Abd et al. 2009). Increasing salinity may be associated with changes in the relative abundance of cations (Na^+, K^+, Mg^{2+}, Ca^{2+}) and anions (Cl^-, SO_4^{2-}, HCO_3^-) as less soluble species precipitate, or create salt-dependent stratification that can become a barrier for oxygen movement resulting in anoxia (Nielsen et al. 2003).

Several studies indicate that increasing salinity in freshwater ecosystems is associated with decreases in species richness and productivity of some species (Nielsen et al. 2003). For example, abundance of freshwater micro-invertebrates such as rotifers and micro-crustaceans decreases when water salinity exceeds 2 g/L (Dunlop et al.. 2005). Several studies indicate that increasing salinity in freshwater ecosystems is associated with decreases in phytoplankton species richness and productivity, affecting desmids and diatoms such as genus *Cosmarium, Staurastrum, Euastrum,* and *Skeletonema* (Hasle and Evensen 1975, Hasle and Evensen 1976, Flameling and Kromkamp 1994). However, other freshwater phytoplankton such as the green algae *Oocystis* sp. and *Crucigenia* sp. are quite tolerant of higher salinities up to 4.5 g/L (Marcarelli et al. 2006). In the Mesopotamian marshes, brackish diatoms such as *Cyclotella meneghiniana* Kützing, *Nitzschia fasciculata* (Grunow) Grunow*,* and *Pleurosigma delicatulum* W.Smith have been recorded (Al-Zubaidi et al. 2006).

Salinization can cause detrimental effects on crop growth and yield (Chessman and Williams 1974, Blinn 1993). High salt levels, especially in the sediment, have a dramatic impact on plant root zones, which can decrease the ability of plants to absorb water through their roots via osmosis, cause leaf burn and necrosis, and create nutrient and ionic imbalances resulting in poor growth or mortality (Brinkman 1980).

Salinity has a greater effect on the early stages of animals (eggs and larvae) compared to mature individuals (Nielsen et al. 2003). For example, Skinner et al. (2001) showed that elevated salinity may prevent emergence of microfouna from resting eggs. Nielsen et al. (2003) refer to different studies indicating that elevated salinity can block hatching of the rotifer *Brachionus plicatilis* Müller.

Salinity can increase the effect of toxic materials that cause physiological changes and mutations (Bailey and James 2000). In addition, increasing salinity can affect microbial communities, especially ones that have a significant role in nitrogen fixation (Marcarelli et al. 2006), de-nitrification, phosphorus cycling, and carbon cycling (Nielsen et al. 2003). For example, the efficiency of nitrogen fixation of Cyanobacteria dramatically decreases with increasing salinity up to 7 g/L (Marcarelli et al. 2006).

The indirect effects of increased salinity in freshwater systems can include changes in underwater light availability by increasing the aggregation and flocculation of suspended matter, which in turn can also have a dramatic impact on the cycling of energy and nutrients. Water clarity has implications for the formation of cyanobacterial blooms, which remove nutrients from the water and make them unavailable to other, desirable pelagic organisms (Donnelly et al. 1997).

Salinization is a major threat to human health. Saline water is not potable and desalination is very expensive, especially in Iraq where infrastructure is limited. Elevated salinity can reduce crop yields and damage infrastructure. As mentioned in Section1.1.2, the marsh Arabs who reside in the marshes are totally dependent on marsh resources. Increasing salinity levels of the marshes can impact their livelihood by rendering water non-potable, reducing the natural resources of the marshes such as fish and birds, and impacting their livestock, such as water buffalo.

2.2 Aim of this Chapter

In this chapter I address the following questions:

- How has the hydrology and salinity of the Tigris and Euphrates Rivers changed?
- How has the salinity of the marshes changed in the last three decades? And what are the main causes?
- Will the salt content of the re-flooded marshes continue to increase?

In order to answer these questions I will:

  - Compare the historical data (flow, volume, salinity) of the Tigris and Euphrates Rivers to their status during the study period.
  - Compare the salinity of the Mesopotamian marshes before and after the desiccation period and re-flooding.
  - Investigate the sources and processes contributing to increased salinity of the marshes after re-flooding by producing a salt budget for the Al-Hawizeh, Central and Al-Hammar marshes.

2.3 Sampling Sites Description

The direct water inflows and outflows of the Mesopotamian marshes (Figure 2–4, Table 2–1) were monitored monthly for water discharge (WD) and salinity from May 2006 to February 2007 for the Central and Al-Hammar marshes, and from May 2006 to March 2007 for the Al-Hawizeh marsh.

The Al-Hawizeh marsh has four constant water inputs from distributaries of the Tigris River (stations 1 to 4 in Figure 2–4). Due to logistical difficulties, including security concerns, water flow from the Al-Sannaf marsh, north of Al-Hawizeh, and seasonal water input from Iran through Al-Karkha River were not monitored during the study period. The Al-Hawizeh marsh has two outlets (stations 5& 6 in Figure 2–4). The Central marshes have ten water inputs; Al-Gharraf, a distributary of the Tigris River, and nine channels from the Euphrates River (station 7 to 17 in). These nine channels of the Euphrates River also act as outlets when the water level in the river decreases to below that of the marsh. Historically, Al-Hammar marsh was fed naturally by the Euphrates River via Al-Kirmashia tributary and through seasonal discharge from Central marshes, while the Al-Mashab River was the main outlet of the marsh into Shatt Al-Arab (station 20 in Figure 2–4). During 1990s, several channels were constructed to balance the water level in the Euphrates River during the desiccation process of the Al-Hammar marsh. Since re-flooding, the Al-Kirmashia River has remained closed and the only water source into the Al-Hammar marsh is via three constructed channels that remained operating (stations 17 to 19 in Figure 2–4), which are influenced by the twice-daily tidal surge of the Shatt Al-Arab River (IF 2003).

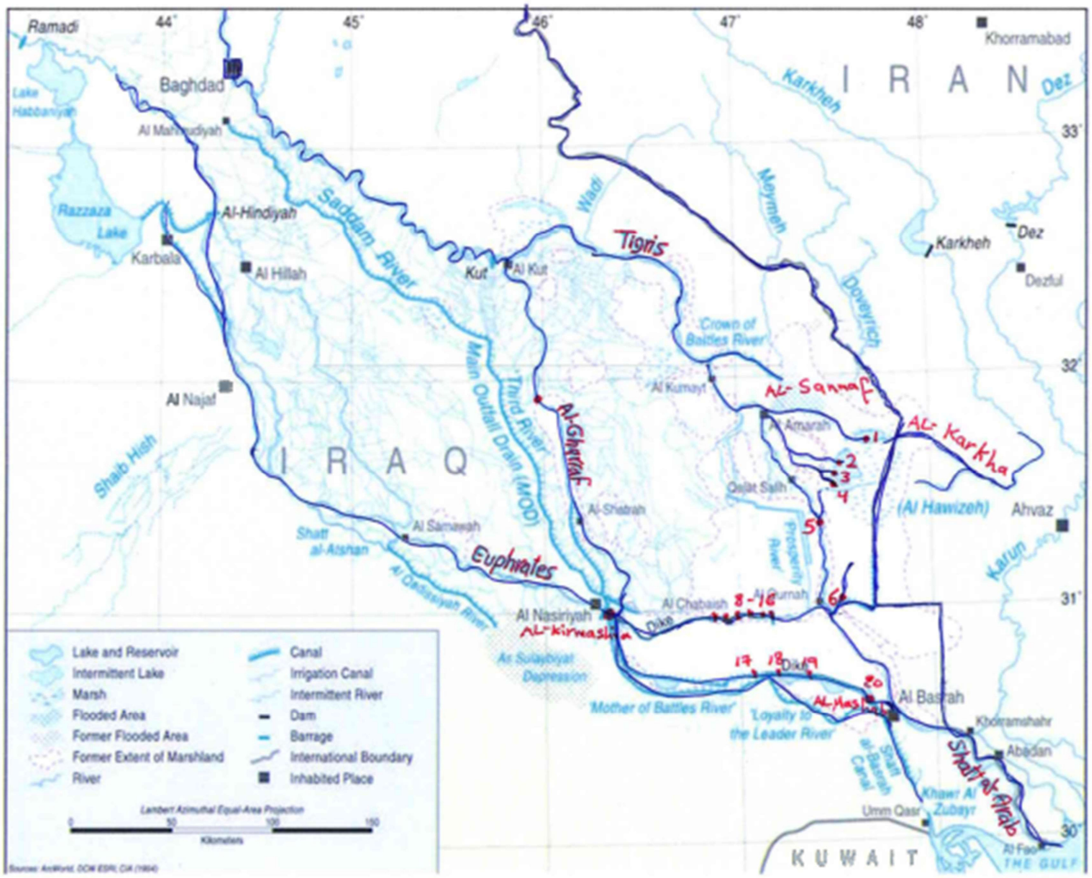


Figure 2–3: The water inputs and outlets (1 to 20) of the Al-Hawizeh, Central and Al-Hammar marshes during the study period.

Table 2–1: The water inputs and outlets (1 to 20) of the Al-Hawizeh, Central and Al-Hammar marshes during the study period.

Sampling stations	**Latitude (N)**			**Longitude (E)**			**Site description**
Al-Hawizeh marsh							
Al-Msharah (1)	31	42	16	47	36	6	Water input
Al-Zubair (2)	31	38	56	47	34	38	Water input
Um Al-Toos (3)	31	37	0	47	33	8	Water input
Al-Husachi (4)	31	34	4	47	30	3	Water input
Al-Kassara (5)	31	21	39	47	26	57	Water outlet
Al-Sweeb (6)	30	58	6	47	29	28	Water outlet
Central marsh							
Al-Gharaf (7)	31	9	52	46	36	40	Water input
Abu Sobatt (8)	30	58	6	47	2	20	Input and outlet
Abu Al-Narssi (9)	30	58	4	47	3	40	Input and outlet
Abu Cholan (10)	30	58	16	47	1	20	Input and outlet
Al-Subagaia (11)	30	58	6	47	9	3	Input and outlet
Al-Khainziry (12)	30	58	4	47	8	24	Input and outlet
Abu Jathiaa (13)	30	58	2	47	9	27	Input and outlet
Sabaa (14)	30	58	1	47	8	1	Input and outlet
Al-Baderia (15)	30	58	8	47	10	15	Input and outlet
AlKhiala (16)	30	58	9	47	10	42	Input and outlet
Al-Hammar marsh							
Al-Mansoury (17)	30	40	28	47	37	41	Input and outlet
Al-Dawadi (18)	30	39	33	47	39	35	Input and outlet
Al-Shafia (19)	30	51	17	47	32	10	Input and outlet
Al-Meshib (20)	30	40	49	47	37	39	Outlet

Within the three marshes, 35 stations were monitored for salinity (Figure 2–4; Table 2–2). The salinities recorded during 2004 to 2008 from the 35 stations were compared; however, only salinity from 2006 – 2007 at stations monitored during the Nutrient Budget (NB) and Canadian – Iraq Marshlands Initiative (CIMI) I surveys (refer to Table A1 for monitoring surveys and Table A2 for monitoring station locations in Appendix 1) was used to calculate the salt budget.

Figure 2–4: A satellite image showing the water inputs and outlets (1 to 20) and monitored stations (21 to 47) of the Al-Hawizeh, Central and Al-Hammar marshes during the study period. Source: U.S. Department of State Geographer.

Table 2–2: Latitudes and longitudes of the sampling stations.

Sampling stations	Latitude (N)			Longitude (E)		
Al-Hawizeh marshes						
Al-Udhaim (21)	31	41	30	47	44	0
Um Al-Niaaj (22)	31	36	0	47	36	0
Al-Souda North (23)	31	40	23	47	40	0
Um Al-Warid (24)	31	34	47	47	31	7
Al-Souda South (25)	31	25	15	47	36	56
Al-Baydha (26)	31	22	1	47	38	46
Majnoon (28)	31	7	59	47	35	33
Lissan Ijerda (27)	31	17	27	47	34	37
Central marshes						
Al-Sewelmat (28)	31	28	27	47	3	41
Al-Baghdadia (29)	31	1	20	47	2	14
Abu Zarag (30)	31	8	57	46	37	16
Badir Al-Ramaidh (31)	31	5	30	46	39	51
Al-Bsaida (32)	30	59	35	47	13	14
Zichri (33)	31	3	19	47	13	19
Al-Muajid (34)	31	5	0	46	38	3
Al-Fuhod (35)	30	59	10	46	43	32
Al-Hammar marshes						
Al-Auda (36)	31	38	29	46	51	5
Al-Nagara (37)	30	40	4	47	38	38
Al-Burka (38)	30	52	41	46	56	2
Al-Tina (39)	30	53	59	46	51	59
Al-Bhayra (40)	30	46	54	47	3	1
Um Nakhla (41)	30	49	16	46	38	32
Al-Khwasa (42)	30	46	41	46	39	27
Shweria (43)	30	46	57	46	37	28
Al-Jeweber (44)	30	56	45	46	36	55
Al-Kurmashia (45)	30	47	56	46	37	25

2.4 Materials and Methods

Obtaining sufficient recent data was a challenge due to the paucity of records. For many years, relevant ministries in Iraq faced difficulties in collecting monitoring data as a result of military conflict between Iran and Iraq, and desiccation of the marsh areas. The historic data, albeit old, are relatively complete.

2.4.1 Changes in the Hydrology of the Tigris and Euphrates Rivers

Annual WD (m^3/y) from 1940 to 2005 for the Tigris River was obtained from Saleh (2010) and for the Euphrates River was obtained from Al-Manssory (2008). Linear regression was used to illustrate the reduction in the WD over time using SigmaPlot version 12.3.0.36.

Monthly WD (m^3/s) data for the Tigris and Euphrates Rivers from 2003 – 2007 was taken from MoWR (2011). Data from before dam construction (1937 – 1973) and post-dam construction (1974 – 1998) were taken from Partow (2001).

2.4.2 Changes in Salinity in the Tigris and Euphrates Rivers

Average monthly discharge-weighted salinity (g/L) data of the Tigris and Euphrates Rivers from 1958 – 1959 were obtained from Rzoska (1980). Average monthly discharge-weighted salinity of the main water inputs of the Tigris and Euphrates Rivers into the marshes from 2006 – 2007 was estimated using salinity data collected with a Wissenschaftlich-Technische Werkstätten (WTW) multi-meter model 350i, Germany. The meter reported salinity as ppt, but it is reported here as g/L.

2.4.3 Change in Salinity of the Mesopotamian Marshes

Salinity of the Mesopotamian marshes from 1978-1979 (Maulood et al. 1979); 1983-1985 (Al-Lami 1984; Al-Zubaidi 1985), 2004 (Richardson and Hussain, 2006), and 2005 through to 2008 (obtained from the multiple surveys conducted on the Mesopotamian marshes; see Table A1 in

Appendix 1) were used to investigate the changes in salinity level of the Mesopotamian marshes overtime.

2.4.3.1 Salinity Increase due to Surface Water Input

Salinity of the direct water inputs of the Al-Hawizeh from May 2006 to March 2007, and the Central and Al-Hammar marshes from May 2006 to February 2007, was monitored monthly to investigate the increase of salinity due to surface water inputs.

2.4.3.2 Estimation of WD and salinity

Monthly WD from the Al-Sannaf marsh from May 2005 to February 2006 and the monthly rainfall from May 2004 to February 2005 were taken from MoWR (2011), while the average monthly Iranian WD via the Al-Karkha River from May 1998 to February 1999 was taken from Iranian Ministry of Environment (2004). Monthly WD of the inputs and outputs described in section 2.3 of the Al-Hawizeh marshes from May 2006 to March 2007 and water inputs of the Central and Al-Hammar marshes from May 2006 to February 2007 were monitored during the study period. Water velocity and salinity were measured using a HYDRO BIOS current meter, mounted on a rod and the WTW multi-meter. Where depth exceeded 1 m, measurements were taken at 20% and 80% of the total depth and then averaged to obtain mean water velocity. If the depth was less than 1 m, then the measurements were taken at 60% of the total depth. River discharge was computed by multiplying the area of the channel cross-section by the average velocity of the water in that cross-section.

Monthly water loss via evapotranspiration (*Evpt*) was calculated by taking the difference between water inputs (surface input + rainfall) and outputs. Salt inputs and outputs were estimated as the product of salinity and discharge.

Residence times are calculated according to the fractal freshwater method (Mitsch & Gosselink, 2007) which requires as input parameters: riverine discharge (§3.1.5) and estuarine volume (based on the topo-bathymetry, see §3.1.1 and §3.2.1).

2.4.4 Salt Balance Calculation

Salt balance of Al-Hawizeh from May 2006 to March 2007 and the Central and Al-Hammar marshes from May 2006 to February 2007 were calculated by taking the difference between the salt inputs and exports as shown below and assuming that the salinity of rainfall is zero. Residence times of the Al-Hawizeh, Central, and Al-Hammar marshes were calculated according to the fractal freshwater method (Mitsch and Gosselink 2007) as $\frac{V}{I}$,

where V is the volume of the marsh and I is the water input in volume per time.

2.5 Results

2.5.1 Changes in the Hydrology of the Tigris and Euphrates Rivers

2.5.1.1 Water Reduction

There has been a reduction in the annual WD of the Tigris and Euphrates Rivers over time (Figure 2–5). The annual WD of the Tigris and Euphrates pre-desiccation in 1993 were ranged from 263 m^3 to 1881 m^3 and from 285 m^3 to 2008 m^3, respectively based on annual WD from 1940 to 1992. After re-flooding from 2003 to 2005, the WD of the Tigris and Euphrates were ranged from 187 m^3 to 289 m^3 and from 263 m^3 to 285 m^3, respectively. These averages indicate that the annual WD of the two rivers was reduced to 45% by 2002.

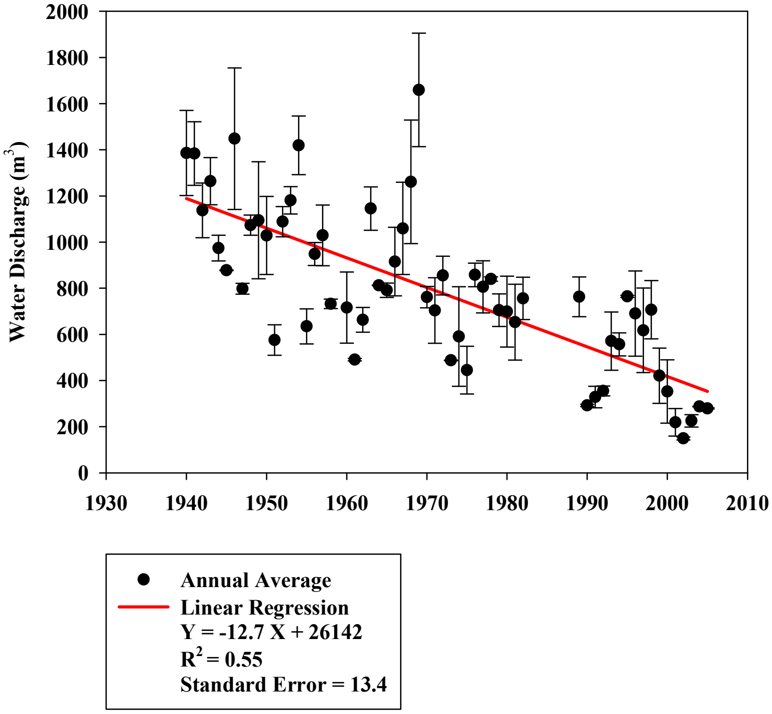


Figure 2–5: The annual average WD (excluding flood years) of the Tigris River (Data from Saleh (2010)) and the Euphrates River (Data from Al-Manssory, 2008) from 1940 to 2005 (excluding flood years 1959 and 1988 and data from 1983 to 1987) measured at the closest input points (Al-Kut and Al-Nasiriya) to the Mesopotamian marshes; bars= standard error.

2.5.1.2 Hydrological Cycle

The annual pattern in discharge of the Tigris and Euphrates Rivers also changed over time (Figure 2–6, Table 2–3). The main hydrological characteristic of the two rivers was the flood season or spring pulse that started in late March and ended mid-May (Figure 2–6). The average monthly WD of the two rivers reached its maximum, 1588 m3/s, in May. A reduction of approximately 89% of the maximum spring pulse occurred late 1980's. In 2006-2007, the average WD of the two rivers was reduced to 292 m^3/s in May. Figure 2–6 also demonstrates a significant shift in the flood period from spring-summer (June and July) during 2002 – 2005 and to fall (November) during 2006 – 2007 (Table 2–3).

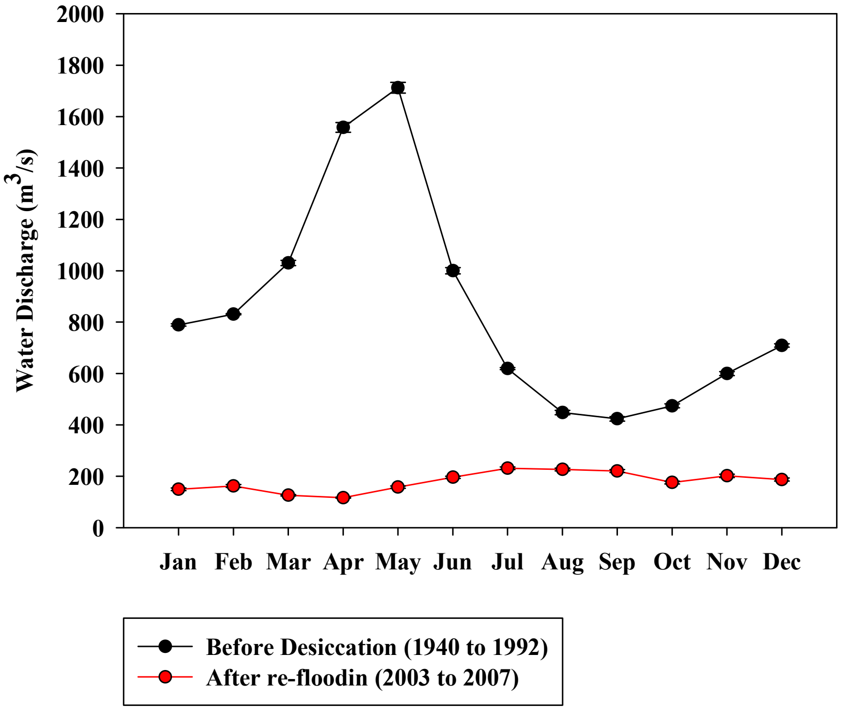


Figure 2–6: The monthly total WD of the Tigris River measured at Al-Kut station and Euphrates River measured at Al-Nasiriya station.

2.5.2 Changes in Salinity of the Tigris and Euphrates

Salinity increased in both rivers over time, especially in the Euphrates (Figure 2–7). The discharge-weighted average salinity of the two rivers in 1958 – 1959 was approximately 0.3 g/L, while their weighted average salinity in 2006-2007 was 0.73 g/L, an increase of 2.6 times. As well, the seasonal pattern in salinity has changed (Figure 2–7, Table 2–3). Salinity during 1958 – 1959 was high during fall, October through December, but did not exceed 0.5 g/L. In spring, March through May, the weighted salinity decreased to 0.19 g/L. During 2006 – 2007, it was high in March with a maximum level 3.4 g/L while in summer, especially June and July; it decreased (Table 2–3).

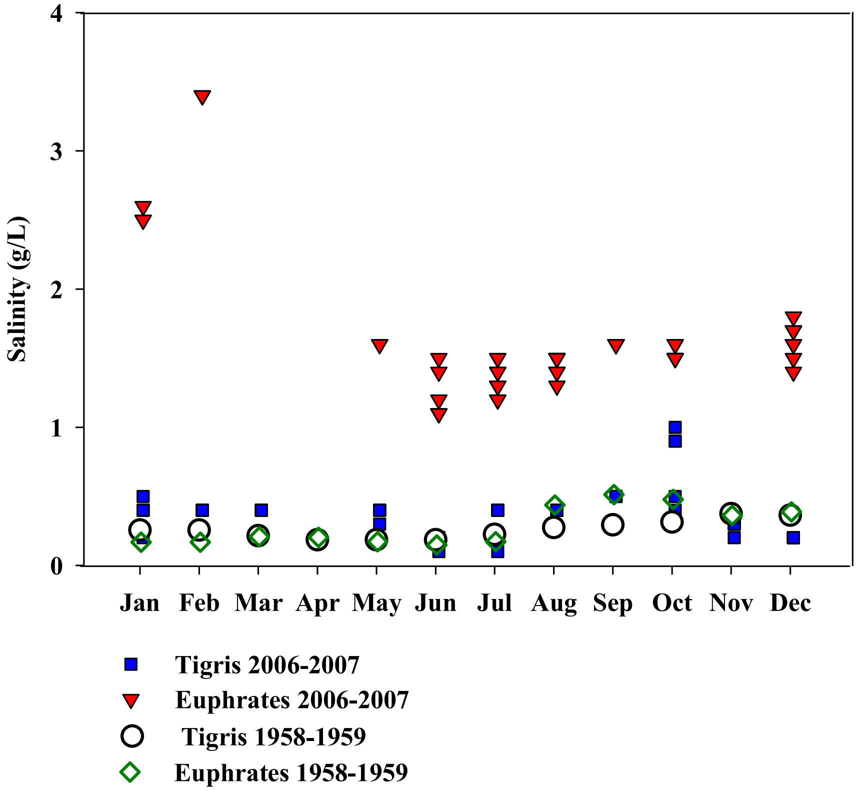


Figure 2–7: Comparison of salinity of the Tigris and Euphrates Rivers between their values pre desiccation (1958 – 1959) and after re-flooding (2006 – 2007).

Table 2–3: Salinity (g/L) of the Tigris and Euphrates Rivers. Stations in *italics* are from Rzoska (1980) during March 1958 to April 1959 before the major dam construction period; superscript a refers to the stations measured during May 2006 to April 2007, and b refers to stations measured during May 2006 to February 2007.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Euphrates												
Al-Nasiriya station	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.5*	*0.5*	*0.5*	*0.4*	*0.4*
Abu Subatt[a]	2.6	3.4				1.1	1.2	1.5	1.6	1.5		1.4
Abu Narssi[a]	2.5	3.4				1.1	1.2	1.4	1.6	1.5		1.5
Abu Juilan[a]	2.5	3.4				1.2	1.3	1.5	1.6	1.5		1.5
Al-Subagaia[a]						1.5	1.4	1.5	1.6	1.5		1.7
Al-Khainziry[a]							1.3	1.4	1.6	1.5		1.6
Abu Jathiaa[a]							1.4	1.5	1.6	1.5		1.7
Sabaa[a]							1.5	1.5	1.6	1.5		1.8
Al-Baderia[a]					1.6	1.1	1.3	1.5	1.6	1.6		1.6
Al-Khiala[a]					1.6	1.4	1.5	1.3	1.6	1.6		1.7
Al-Mansoury[a]	1.4	3.0			1.7	1.5	1.2	1.3	1.5	1.5	1.9	1.8
Al-Dawadi[a]	1.2	4.9			1.5	1.3	1.1	1.2	1.4	1.4	1.9	1.6
Al-Shafia[a]	1.1	1.9			0.9	0.8	1.1	1.1	1.2	1.4	1.3	0.9
Tigris												
Al-Kut station	*0.3*	*0.3*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.3*	*0.3*	*0.3*	*0.4*	*0.4*
Al-Gharraf[a]	0.2	0.4			0.3	0.1	0.1	0.4	0.5	0.4	0.2	0.2
Al-Msharah[b]	0.4	0.4	0.4		0.4	0.2	0.4	0.4	0.5	0.9	0.3	0.2
Al-Zubair[b]	0.4	0.4	0.4		0.4	0.2	0.4	0.4	0.5	0.9	0.3	0.2
Um Al-Toos[b]	0.4	0.4	0.4		0.4	0.2	0.4	0.4	0.5	0.5	0.3	0.2
Al-Husachi[b]	0.5	0.4	0.4		0.4	0.2	0.4	0.4	0.5	1.0	0.3	0.2

2.5.3 Change in Salinity of the Mesopotamian Marshes

The salinity of the Mesopotamian marshes has varied over time (Figure 2–9) increasing from around 0.4 g/L during the pre-desiccation period (1970s) to around 2.5 g/L during 1980s and to an average of 1.2 g/L during the re-flooding period (2004 – 2008).

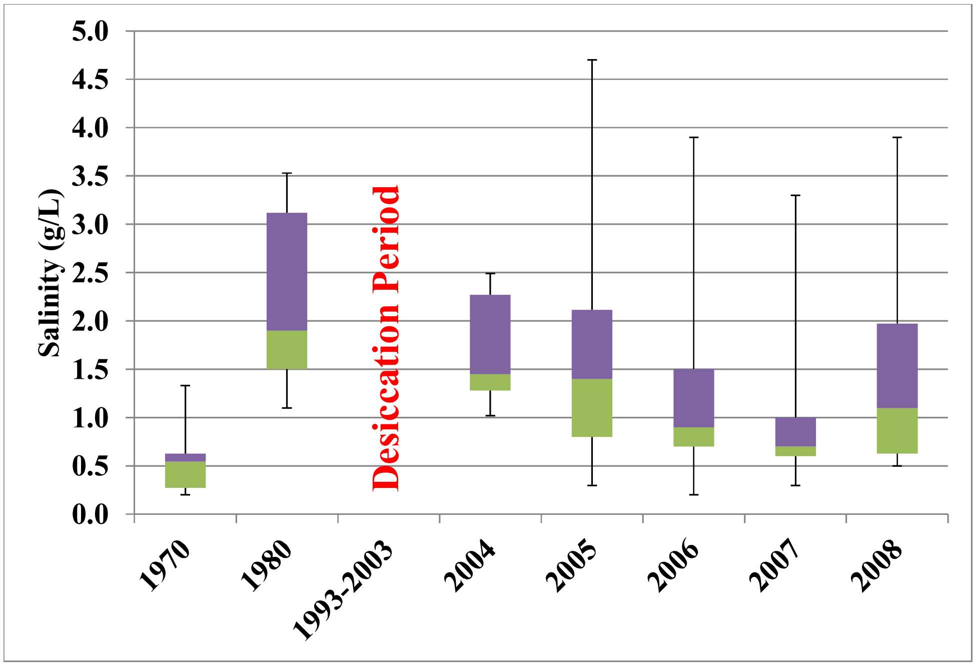


Figure 2–8: Salinity of the Mesopotamian marshes over time. The 1978 – 1979 data are from Maulood et al. (1979); 1983 – 1985data are from Al-Lami (1984) and Al-Zubaidi (1985). The 2004 data are from Richardson and Hussain (2006). The 2005 through to 2008 data are from the multiple surveys conducted on the Mesopotamian marshes (see Table A1 in Appendix 1).

The salinity of the Mesopotamian marshes had a small range in the1970s compared to the 1980s and 2000s. High salinity values ranging from 4 g/L to 8 g/L were observed after re-flooding the marshes. However, most of the salinity values of the marshes after re-flooding were below 2.5 g/L. The median salinity of the marshes is greater than the mean, and this difference has increased over time indicating an increasingly skewed distribution (Table 2–4, Figure 2–8).

Table 2–4: Mean and median salinity of the Mesopotamian marshes over time.

	1970s	**1980s**	**2004**	**2005**	**2006**	**2007**	**2008**
Mean	0.6	2.2	1.7	1.5	1.1	1.0	1.6
Median	0.5	1.9	1.5	1.4	0.9	0.7	1.1

During my study, the salinity of Central and Hawizeh Marshes decreased, and Hammar Marsh increased (Table 2–5). The average salinity of the distributaries of the Tigris and Euphrates to the Mesopotamian marshes was higher than the historical values (refer to section 2.5.2) and the weighted average salinity of the Tigris distributaries was lower than that of the Euphrates distributaries. The monthly average salinity of the Tigris inputs did not exceed 0.9 g/l, while the lowest weighted average salinity of the Euphrates inputs was 0.8 g/L (Figure 2–9). During the study period, the average salinity of the Tigris water distributaries was highest in October 2006, while the weighted average salinity of the Euphrates distributaries was highest in February 2007 (Figure 2–9). The weighted average salinity of the inputs to the Al-Hawizeh marsh during the study period was lower than to the Central and Al-Hammar marshes (Figure 2–10). The low salinity of the water entering the Central Marsh in November 2006 reflects that data were available only for inputs from the Tigris River.

Table 2–5: Salinity (g/L) of the Al-Hawizeh, Central and Al-Hammar water inputs and outputs during the study period.

	May 06	**Jun 06**	**Jul 06**	**Aug 06**	**Sep 06**	**Oct 06**	**Nov 06**	**Dec 06**	**Jan 07**	**Feb 07**	**Mar 07**
Al-Hawizeh water input*											
Al-Msharah	0.4	0.2	0.4	0.4	0.5	0.9	0.3	0.2	0.4	0.4	0.4
Al-Zubair	0.4	0.2	0.4	0.4	0.5	0.9	0.3	0.2	0.4	0.4	0.4
Um Al-Toos	0.4	0.2	0.4	0.4	0.5	0.5	0.3	0.2	0.4	0.4	0.4
Al-Husachi	0.4	0.2	0.4	0.4	0.5	1.0	0.3	0.2	0.5	0.4	0.4
Average	**0.4**	**0.2**	**0.4**	**0.4**	**0.5**	**0.8**	**0.3**	**0.2**	**0.4**	**0.4**	**0.4**
Al-Hawizeh water output											
Al-Kassara	0.7	0.6	0.6	0.7	0.7	0.7	0.7	0.6	0.2	0.5	0.5
Al-Sweeb	1.0	1.1	1.2	1.2	1.3	1.2	1.1	1.0	1.0	1.0	1.0
Average	**0.9**	**0.9**	**0.9**	**1.0**	**1.0**	**1.0**	**0.9**	**0.8**	**0.6**	**0.8**	**0.8**
Residence time (days)	**233**	**391**	**493**	**558**	**468**	**595**	**465**	**363**	**220**	**223**	**202**
Central water input											
Al-Garraf*	0.3	0.1	0.1	0.4	0.5	0.4	0.2	0.2	0.2	0.4	
Abu Subatt**		1.1	1.2	1.5	1.6	1.5		1.4	2.6	3.4	
Abu Narssi**		1.1	1.2	1.4	1.6	1.5		1.5	2.5	3.4	
Abu Juilan**		1.2	1.3	1.5	1.6	1.5		1.5	2.5	3.4	
Al-Subagaia**		1.5	1.4	1.5	1.6	1.5		1.7			
Al-Khainziry**			1.3	1.4	1.6	1.5		1.6			
Abu Jathiaa**			1.4	1.5	1.6	1.5		1.7			
Sabaa**			1.5	1.5	1.6	1.5		1.8			
Al-Baderia**	1.6	1.1	1.3	1.5	1.6	1.6		1.6			
Al-Khiala**	1.6	1.4	1.5	1.3	1.6	1.6		1.7			
Average	**1.2**	**1.1**	**1.2**	**1.4**	**1.5**	**1.4**		**1.5**	**2.0**	**2.7**	
Central water output											
Abu Subatt**	1.3						1.7				
Abu Narssi**	1.3						1.6				
Abu Juilan**	1.4						1.5				
Al-Subagaia**	1.6						1.6		2.1	3.1	
Al-Khainziry**	1.7	1.7					2.1		2.2	2.6	
Abu Jathiaa**	1.7	1.5					2.1		2.2	2.5	
Sabaa**	1.7	1.7					2.0		2.2	2.4	
Al-Baderia**							2.0		2.1	2.3	
Al-Khiala**							2.0		2.2	2.2	
Average	**1.5**	**1.6**					**1.8**		**2.2**	**2.5**	
Residence time (days)	**7685**	**518**	**115**	**202**	**140**	**133**	**276**	**90**	**347**	**453**	
Al-Hammar water input**											
Al-Mansoury	1.7	1.5	1.2	1.3	1.5	1.5	1.9	1.8	1.4	3	
Al-Dawadi	1.5	1.3	1.1	1.2	1.4	1.4	1.9	1.6	1.2	4.9	
Al-Shafia	0.9	0.8	1.1	1.1	1.2	1.4	1.3	0.9	1.1	1.9	
Average	**1.4**	**1.2**	**1.1**	**1.2**	**1.4**	**1.4**	**1.7**	**1.4**	**1.2**	**3.3**	
Al-Hammar water output											
Al-Mashab	1.6	1.5	1.3	1.3	1.6	1.4	1.9	1.8	1.3	3.0	
Residence time (days)	**81**	**99**	**31**	**53**	**59**	**53**	**34**	**78**	**65**	**93**	

* Tigris Distributaries

** Euphrates Distributaries

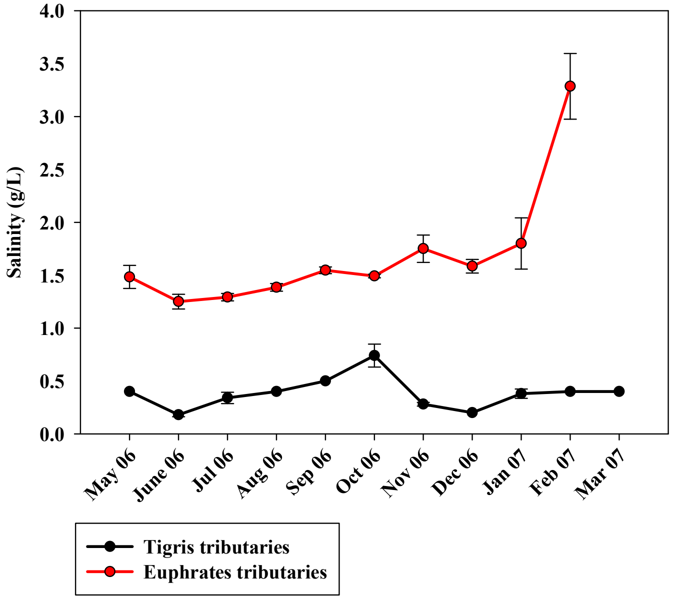


Figure 2–9: Salinity of the Tigris and Euphrates distributaries into the Mesopotamian marshes during the study period. Error bars = standard error.

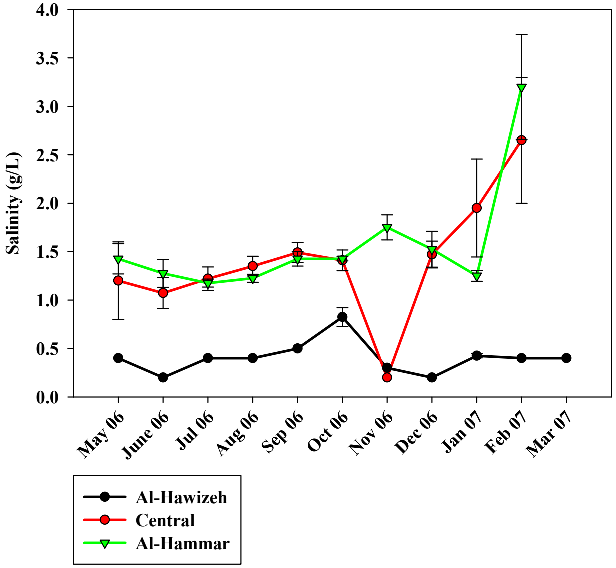


Figure 2–10: Salinity of the Al-Hawizeh, Central and Al-Hammar water inputs during the study period. The salinity of the Central marsh in November was obtained from the Tigris input only since the Euphrates distributaries of the marsh were acting as outlets due to the difference in water level between the marsh and the River. Error bars are standard error.

The salinity of the marshes increases as water travels from input to outlet in Central Marsh (54% increase) and Hawizeh Marsh (80%), but does not increase in Hammar Marsh (Table 2–6). This may reflect that Hammar marsh has a short water retention time and increased in water level during my study, while the other marshes decreased (Table 2–6).

There are several ways examine the salt budget of the marshes (Table 2–6). Calculation 1 in Table 2–6 is based on the difference in salt mass in the marshes at the beginning and end of my study, and estimates that the amount of salt decreased in Central Marsh and Hawizeh, which is congruent with their decline in water level and decrease in salinity. On the other hand, Hammar Marsh appeared to increase in salt content during the study, reflecting that it increased in depth and salinity. Calculation 2 in Table 2–6 estimates the amount of salt entering and leaving the marshes during the study period. It suggests that there has been a net loss of salt from Hawizeh, and a net gain in salt for Hammar. These are congruent with decline in water level and salinity for Al-Hawizeh and the increase in water level for Hammar. However, the calculation for the Central Marsh suggests that much more salt entered than left. This suggests a major problem with the water balance, as reflected by the fact that 12 times more water entered than was discharged. Calculation 3 in Table 2–6 compares the observed salinities (mass/volume) at the end of the study period to the ones calculated from salt inputs and outputs. The agreement is close for Hawizeh, the salinity being only slightly higher than calculated. But for Hammar the observed salinity is almost 40% greater than what I calculate from the inputs and outputs. The discrepancy for Central Marsh is large, with the marsh being much less saline than calculated. This likely reflects the same problem with the water balance as affects the calculation above.

In summary, Hawizeh marsh became slightly less saline during the study period, and lost salt according to calculation 1 while losing depth and volume. Hammar Marsh became more saline and gained salt mass while increasing in volume. However, for Central marsh, the first and second calculations are at odds as the calculated gain in the second calculation is in contrast to the observed loss in calculation 1.

Table 2–6: Calculations showing the changes in salinity of the Al-Hawizeh, Central, and Al-Hammar marshes during the study period.

	Unit	**Central Marsh**	**Hawizeh Marsh**	**Hammar Marsh**
Area	m^2	830,000,000	1,700,000,000	1,050,000,000
Mean depth at start of period	m^2	1.8	2.5	1.4
Mean depth at end of period	m^2	1.6	2.2	1.7
Volume at the start of the period	m^3	1,494,000,000	4,250,000,000	1,470,000,000
Volume at the end of the period	m^3	1,328,000,000	3,740,000,000	1,785,000,000
surface water input	m^3	1,419,136,485	4,018,427,021	6,940,266,754
rainfall input	m^3	273,136,400	289,306,000	717,423,000
total input	m^3	1,692,272,885	4,307,733,021	7,657,689,754
surface water output	m^3	122,992,128	3,214,196,035	6,070,198,406
evapotranspiration during study	m^3	1,569,280,757	1,093,536,986	1,587,491,347
evapotranspiration during study	m/d	0.006	0.002	0.005
Average Salinity observed in the marshes	**g/L**	1.8	0.8	2.2
salinity of the marsh at the start	g/L	1.4	0.8	1.5
salinity of the marsh at the end	g/L	0.7	0.7	2.8
Average salinity of inputs	g/L	1.3	0.5	1.6
Average salinity of outputs	g/L	2	0.9	1.6
output salinity as a % of input salinity	%	154	180	100
% increase in salinity	***%***	***54***	***80***	***0***
Calculation 1				
salt at the start of the study period	kg	2,091,600,000	3,400,000,000	2,205,000,000
salt at the end of the study period	kg	929,600,000	2,618,000,000	4,998,000,000
gain/loss in salt based on concentration	***kg***	***-1,162,000,000***	***-782,000,000***	***2,793,000,000***
Calculation 2				
salt added during study period	kg	1,844,877,431	2,009,213,510	11,104,426,806
salt lost during the study period	kg	237,606,048	2,892,776,432	9,712,317,450
gain/loss based in inputs and outputs	***kg***	***1,607,271,383***	***-883,562,921***	***1,392,109,356***
Calculation 3				
salt at the start of the study period	kg	2,091,600,000	3,400,000,000	2,205,000,000
salt added during the study	kg	1,844,877,431	2,009,213,510	11,104,426,806
salt lost to the outlet	kg	237,606,048	2,892,776,432	9,712,317,450
salt at the end of the study	kg	3,698,871,383	2,516,437,079	3,597,109,356
salinity calculated at the end of the study	***kg/L***	***2.79***	***0.67***	***2.02***
salinity observed at the end of the study	***kg/L***	***0.7***	***0.7***	***2.8***

2.5.3.1 Salt Balance

Looking at the monthly salt balance of the marshes may illuminate underlying processes (Table 2–7, Figure 2–11 and Figure 2–12). The monthly salt balance of the Al-Hammar marshes (Figure 2–11) suggests a close coupling between input and output, but a net gain in salt during all months and overall. Al-Hawizeh (Figure 2–12) showed a weak much weaker coupling between monthly input and output than Hammar, possibly because of its longer water residence time (666 days for Hawizeh marsh compared to 239 days for Central and 69 days for Hammar marshes). On balance, it also appeared to have a net loss of salt and water over the study period, with little change in salinity. For the Central Marshes (Figure 2–13) the lack of measured outflow during several of the months would appear to account for the discrepancy in its budget identified above. Its modest decrease in depth and salinity during the study suggest that nothing unusual is in going on, and that the apparent low discharge of water reflects an error in the measurement of discharge from these marshes.

Table 2–7: Monthly salt balance (kg x 10^3) of the Mesopotamian marshes during the study period.

	Central			**Al-Hawizeh**			**Al-Hammar**		
	Salt input (Si)	**Salt export (Sd)**	**Salt balance (Si-Sd)**	**Salt input (Si)**	**Salt export (Sd)**	**Salt balance (Si-Sd)**	**Salt input (Si)**	**Salt export (Sd)**	**Salt balance (Si-Sd)**
May-06	27.1	30.3	-3.1	401	194	206	870	685	184
Jun-06	59.4	8.2	51.2	188	349	-160	751	666	85
Jul-06	109.8	0.0	109.8	142	365	-222	1063	918	144
Aug-06	147.2	0.0	147.2	113	192	-79	1057	855	202
Sep-06	195.6	0.0	195.6	131	109	21	1342	1104	238
Oct-06	166.1	0.0	166.1	140	88	52	1018	877	141
Nov-06	26.1	90.4	-64.3	96	360	-264	1746	1606	140
Dec-06	239.7	0.0	239.7	105	269	-164	873	834	39
Jan-07	83.2	34.0	49.2	637	347	290	697	571	126
Feb-07	136.3	50.4	85.9	463	349	114	1892	1475	417
Mar-07	NM	NM		446	353	93	NM	NM	

NM = Not Monitored

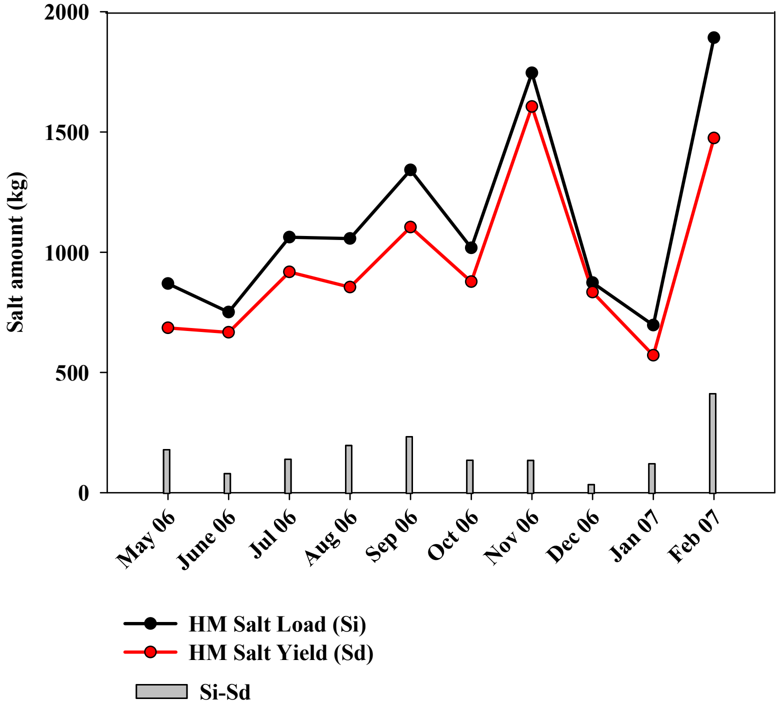


Figure 2–11: The salt budget of the Al-Hammar marshes during 2006-2007.

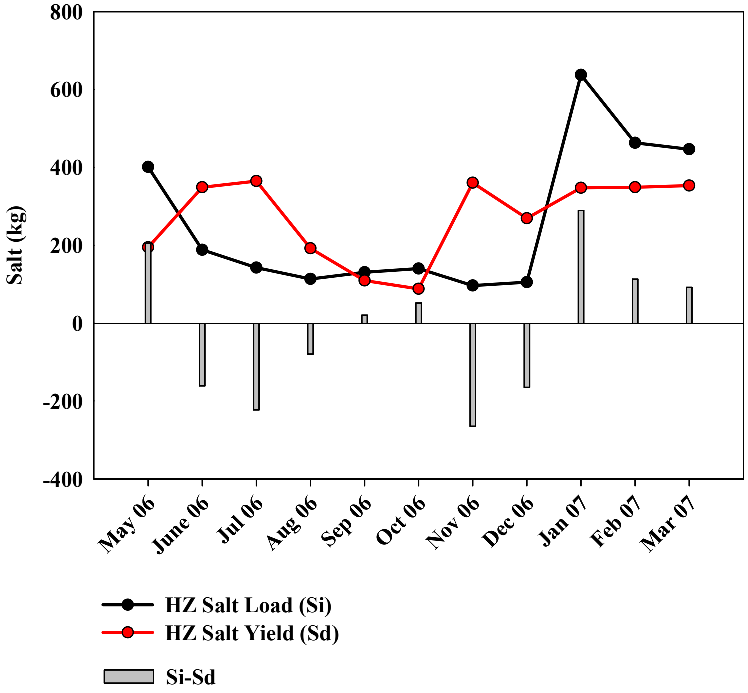


Figure 2–12: The salt budget of the Al-Hawizeh marshes during 2006-2007.

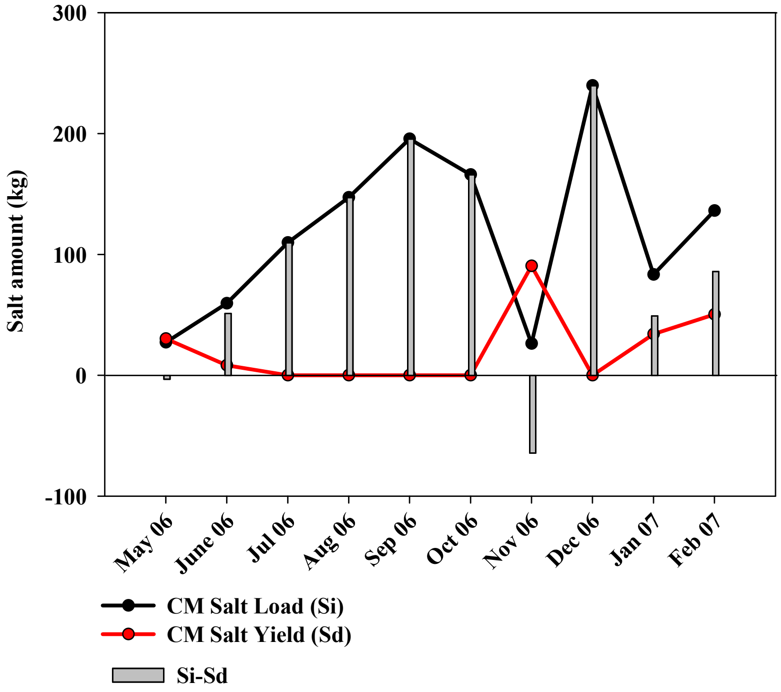


Figure 2–13: The salt budget of the Central marshes during 2006 – 2007.

The monthly variation of the salt budget of the Al-Hawizeh marshes (Figure 2–12) indicates that there is a net export of salt during summer and fall and a gain in salt during the winter and spring. In all three marshes, salinity and depth demonstrate weakly opposite trends (Figure 2–14).

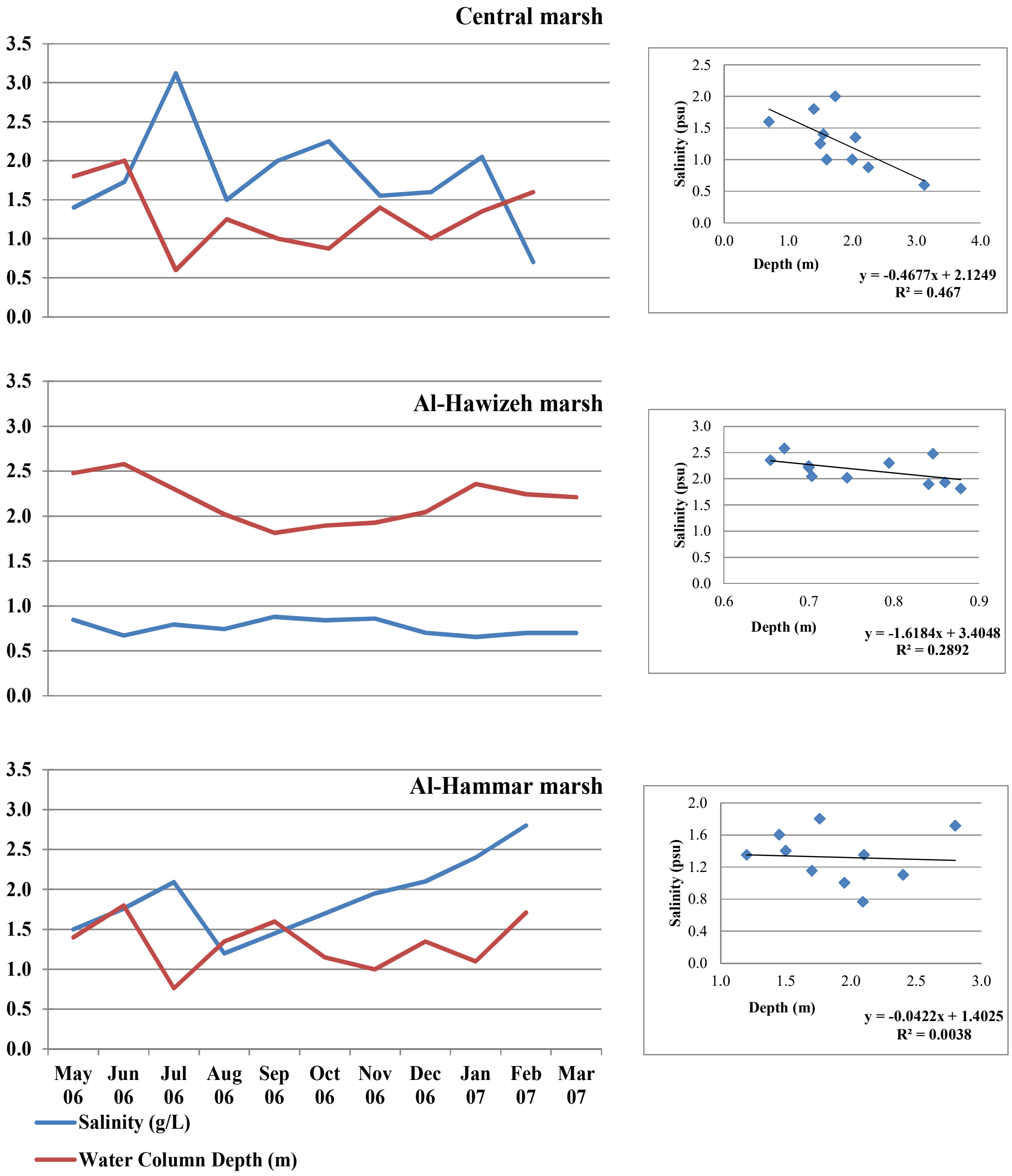
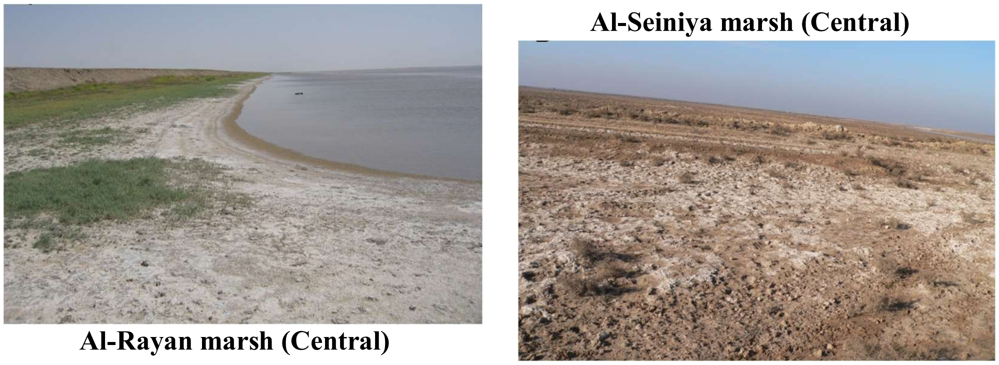


Figure 2–14: Monthly variation in average salinity and water column depth in the Mesopotamian marshes during the study period.

2.5.3.2 Salt Re-dissolution

The government constructed major hydraulic regulators and embankments to block the water entering the marshes; areas that were previously flooded desiccated gradually leaving a thick salty layer on top of the dried sediments (Figure 2–15). Flooding likely re-dissolved the salt crust from the sediment back into the water potentially increasing salinity in the re-flooded areas. Salinity decreased during the years after re-flooding (Figure 2–8), perhaps indicating the loss of this accumulated salt. Both the Hammar marshes and the Al-Hawizeh increased in salinity between inputs and outputs during the study period, although not markedly more than expected from calculation 3 in Table 2–6.



Al-Rayan marsh (Central)

31° 34’ 42” N 47° 2’ 0” E

Al-Seiniya marsh (Central)

31° 55’ 10” N 46° 45’ 50” E

Figure 2–15: Accumulated salt visible on desiccated marsh sediment (pictures were taken by the Marine Science Centre Team during the CIDA field survey in March 2007).

2.6 Discussion

2.6.1 Increasing Salinity of the marshes

The possible contributions to increased salinity of the Mesopotamian marshes from their historical values are the increasing salinity of the inflowing rivers, increased water residence time and hence increased evapotranspiration, and re-dissolution of salts. In this chapter I have examined the increase in salinity of the Mesopotamian marshes over time and during my study. The results suggest that the increase in salinity of the Mesopotamian marshes from 1980s to 2008 is due to: 1) an increase in salinity of the Tigris and Euphrates rivers that supply water to the marshes (Figure 2–7); and 2) evaporative concentration of salts within the marshes, particularly Hawizeh with its long water residence time. The data provided no strong evidence that the salinity of the marshes was still being augmented by re-dissolution of salts during the study period, 2006 – 2007, although the Al-Hawizeh marshes did appear to be losing salt and have a higher salinity than I calculated based on inputs and outputs. Nor do these data indicate that intrusion of salt water into Al-Hammer is increasing with diminished flow of the Euphrates River, as inflow and outflow salinity of this marsh are close to equal. Although the average salinity of water inputs and outlets of Hammar marsh were the same (1.6 psu), the increase in the average salinity of the marsh itself over the study period from 1.5 to 2.8 may be a reflection of high salinity in certain areas with a longer residence time and unregulated agricultural drainage discharge that contains high amount of dissolved salts.

I could not do a satisfactory salt budget for Central marshes because of the uncertain hydrology. The data in Figure 2–13 include a high level of error due to several technical field limitations, irregularities in measuring WD, and irregularities in water flow through the water pipes and regulators. My field observations indicate that the MoWR is not controlling water discharge into the Central marsh, especially in the remote areas, and local communities can open and close the water control structures on the Tigris and Euphrates distributaries without permission. These are the main problems that led to have differences between the estimated water input and output of the Central marsh, and its problematic water and salt budgets. Field observations and the calculations in Table 2–

6 suggest that the water budgets of the Al-Hawizeh and Al-Hammar marshes are better quantified by the MoWR than the Central marsh.

2.6.1.1 Increase salinity of the marshes due to freshwater shortage

The dramatic changes in the hydrological regime of the Tigris and Euphrates Rivers include a significant reduction in discharge over time. I estimate that the reduction in freshwater discharge entering Iraq in 2002 to be about 55% since the onset of major dam construction in 1974. The Tigris and Euphrates rivers have lost about 144 km^3 of freshwater discharge from 2003 to 2009, which is equal to the volume of the Dead Sea (Chillymanjaro 2013). He estimated the water loss as about 60%, enough to cause critical water scarcity for drinking and irrigation. Reduced freshwater input to wetlands has a negative impact on open-water habitat and fish stocks (Turek et al. 1987, EPA 2008). Other effects may include decreased water storage, creation of physical barriers and isolation of marsh units, reduction in fluxes of nutrients and sediments, and reductions in dissolved oxygen (Mitsch and Gosselink 2007). Turek et al. (1987) reviewed more than 120 studies published from 1961 to 1984 investigating the influence of decreasing freshwater inflows on estuarine systems. He conclude that changes in quantity of fresh water input caused significant changes in water quality. For example, Adams (1963), Nestler (1977), and Smart et al. (1978) discuss the impact of increasing salinity due to shortage in freshwater discharge. They found that freshwater inflow/salinity fluctuation reduced seed germination and plant growth and biomass. They also found that increasing salinity due to low freshwater discharge causes succession among emergent plant species and alterations in fluxes of nutrients and suspended particulates. For example, Nixon (1981) concluded that nutrient recycling and re-mineralization associated with pulses of freshwater have a significant contribution to estuarine productivity. Aleem (1972) concluded that the reduction in the peak flow of the Nile caused by the Aswan Dam reduced the catch of sardines in adjacent areas of the Mediteranean Sea from 4600 metric tons in 1965 to 544 in 1966. Beaumont (1998)and Chen et al. (2011) investigated the impact of descreased flow in the Tigris and Euphrates Rivers. Beaumont (1998) conclude that the changes in water management of the Tigris-Euphrates basin in Iraq since 1970s have had, and will continue to have, major consequences, especially for the agriculture of the riparian nations. Chen et al. (2011)

found that the area of the Mesopotamian marshes was significantly reduced during the late 1980s and 1990s, and this reduction in area was the main cause of damage to the marshland ecosystem including wildlife and vegetation.

2.6.1.2 Increase salinity of the marshes due to changes in the salinity of the feeding rivers

Significant increases in salinity have accompanied the decrease in flow of the rivers (Mathews and Shealy 1982, Mohammad 2002, Islam and Gnauck 2007). This is particularly true of the Euphrates River mostly because; 1) the differences in the geology and basin structure between the river (Euphrates basin is mostly sodium carbonate, while Tigris basin is mostly consist of calcium and magnesium carbonate), 2) the lower basin of the Euphrates is affected by agricultural discharge, 3) unlike the Tigris river, the Euphrates does not acquire freshwater inputs once it enters Iraq, while the Tigris is fed by freshwater discharge from Iran (Rzoska 1980). In both cases the increase in salinity mirrors the decrease in flow. The increase in salinity of the rivers is largely explicable by increased evaporation rather than due to a change in rainfall or water removal. Mohammad (2002) and Islam et al. (2007) investigated the major factors causing increased salinity in rivers in Bangladesh. They found that one of the major factors leading to salinization is intrusion of sea water due to the reduction of freshwater flow and indicated that the diversion of Ganges at Farakka Barrage in India from early 1975 caused a significant increase in salinity, especially in the south western part of Bangladesh. They also showed that this action negatively affected the urban drinking water supply, industrial production, agriculture, and fisheries. However, we found no evidence of seawater intrusion into Al-Hammar marsh, even though it is affected by tides via the Shatt Al-Arab; the input and output salinities were similar.

2.6.1.3 Increasing salinity of the marshes; evapotranspiration versus re-dissolution of salts

Historically, salinity of the Mesopotamian marshes showed modest seasonal variation, with lower salinity (< 0.5 g/L) occurring in winter and higher salinity (> 0.5 g/L) during dry periods (July to

October) due to high evapotranspiration rates and relatively low flow (Hussain 1994). This regime prevailed in the 1970s (Figure 2–8). Although there are no data on the temporal or spatial variation of salinity during the period from 1980 to 2005, such variation would be expected as a result of a reduction in depth and flushing rate of the marshes that would magnify the effect of evapotranspiration on salinity. Field observation by MoWR in early 2003 as well as my observations during the CIMI project in 2007 (Figure 2–15) indicate that salt deposits in the marshes, a result of the drying of the marshes during 1993 to 2003, were the main cause of high salinity during the first years of inundation in 2004 and 2005. Fitzpatrick (2004) and Richardson et al. (2005) concluded that flooding the dry marsh soil led to dissolution of the salt crust from the sediment and a high salinity of the newly re-flooded marshes. However, the increase in salinity of the marshes during 2006 – 2007 was similar to the expectation based on the net loss of water. Given the residence time of water in the marshes (69 to 666 days) the salt deposited during desiccation should have been flushed before the study period except possibly in Hawizeh.

2.6.2 What salinity is acceptable and whether that is likely to be achievable

There is no universal standard for salinity of freshwater marshes. According to the Americas Wetlands Resource Centre, salinity of freshwater marshes ranges between 0 and 2 psu. The Groundwater Foundation and the United States Office of Naval Research suggest that the salinity of freshwater marshes should not exceed 0.5 psu, while the National Centre for Atmospheric Research (UCAR), USA, defines freshwater as less than 1 psu. I suggest that the average salinity of the marshes should not exceed 1 psu to maintain their characteristics as freshwater wetlands, based on the historical values for salinity of the Mesopotamian marshes (Figure 2–8).

My analysis shows that the Al-Hawizeh marsh has a better chance to maintain an acceptable salinity value providing that the water supply and the salinity of that supply do not deteriorate further. Since the Tigris is less saline than the Euphrates, salt loads into Al-Hawizeh are lower than into Al-Hammar marsh (Table 2–6). Al-Hammar marsh has less chance to reach the acceptable salinity value due to the high salinity of the Euphrates River and the threat of invasion of seawater should discharge decline further. The variable operation of water control structures and an irregular water supply contributes to the variability in salt load and salinity of the marshes. The problems in calculating the salt budget of the Central Marsh creates uncertainty as to whether this marsh will be able to maintain reach an acceptable salinity. According to the hydrological status of the Mesopotamian marshes and the changes in the hydrological regime of the Tigris and the Euphrates Rivers, maintaining enough water supplies to the marshes will be problematical. Abdul Latif Rashid, the former Minister of Water Resources for Iraq (2003 – 2011, indicated that the current hydrological regime in Iraq is unstable and that water entering Iraq via the Tigris River will be reduced to 312 m^3/s with the completion of the Aliso dam, which will have serious consequences for the environment (IRAQ Directory 2007). Clearly, the Mesopotamian marshes recovery plan suggested by the Italian Ministry of Environment and Territories (IMET 2006) will face challenges including another period of desiccation. Based on the water quantity and quality reductions of the Tigris and Euphrates Rivers that have been observed, the Iraqi government must plan and manage the re-flooding process and should take under consideration water shortage, global warming, and competing water usage. Alternative water sources like MOD have to be under intensive regulation. MOD water has to be desalinized and treated before use. Groundwater can be another source of water; however, strategic studies have to be done to investigate the amount of ground water available and its quality.

Reduced WD in the two rivers and the unavailability of alternative water supply makes the government unable to provide sufficient water supply to the marshes to increase the flushing rate and reduce the salinity. The flushing of the marshes is no longer a seasonal occurrence and salinity increases 54% and 80% from inlet to outlet in the Central and Al-Hawizeh marshes, respectively, presumably due to evaporation. Based on current water quantity and quality, I believe that only the Al-Hawizeh marshes will be able to maintain salinities less than 1 psu. According to the MoWR, 2006 – 2007 was an optimal year for water supply (Iraqi MoWR internal report, 2011) yet parts of the marshes were still too saline. The MoWR reported that during 2006 – 2007 re-flooding allowed the marshes to reach 52% of their historical size, the maximum since April 2003 (Al-Manssory 2008). However, the Iraqi MoWR reported in 2011 that due to water shortages the re-flooded marshes were reduced to 45% of their historical size and 20% of the re-flooded sub-marshes were completely dry. The current unregulated flooding process will not be able to restore the historical size of the marshes while avoiding salinities increasing significantly above the input level. It is important that the salinity of the Mesopotamian marshes be monitored, at least at their outlets, to quantify how salinity changes with area. A hydrological model should be designed to investigate how the salinity of the marshes changes with WD of the rivers.

Chapter 3

Water Quality Assessment of the Re-flooded Mesopotamian Marshes

3.1 Introduction

3.1.1 Hydrological Impact on the Mesopotamia's Water Quality

The significant reduction in freshwater entering the Mesopotamian marshes (refer to section 1.1.3.1in Chapter 1), the changes in the hydrological characteristics of the marshes' water sources (refer to section 1.1.3.5in Chapter 1), and the increase of the agricultural discharge could have a negative impact on water quality and the recovery processes of the re-flooded marshes (IF 2003, IMET 2006, Richardson et al. 2005, Warner et al. 2011). Richardson et al. (2006) investigated the limitations that affect the recovery potential of the newly re-flooded marshes. They concluded that complete recovery is a serious challenge because of the water shortage and the lack of water management. The former (2003 – 2011) Minister of Water Resources, Dr. Abdul Latif Rashid, stated that political conflict between Iraq and the upstream countries is the main barrier to agreement on water quotas for each country (IRAQ Directory 2007). Warner et al. (2011) discussed the water conflicts and the difficulties of providing sufficient and consistent water to inundate the historical area of the Mesopotamian marshes. Since the amount of water entering Iraq has been reduced dramatically and is unpredictable, water distribution in Iraq is now controlled. The priority is to maintain reservoir levels and provide for irrigation (Al-Manssory 2008). Thus, the re-flooded marshes are now receiving much lower water quantities (IMET 2006).

Recovery of the marshes requires an adequate quantity of water, but also water of good quality. Water quality is determined by the physical, chemical, and biological characteristics of the water (EPA 2002, WHO 2004). These characteristics are often referred to as water quality parameters (WQP) and are used to describe the condition of the aquatic environment (Cole 1983, Stumm and Morgan 1996, Boulton and Brock 1999, Wetzel 2001). However, there is no single parameter or set of parameters that constitute good water quality because water has different uses that require different quality standards (EPA 2003). Therefore, parameters for water quality are determined by the intended use, for example, human consumption, industry, provision of wildlife habitat, fishing or irrigation (Johnson et al. 1997).Water quality criteria for the protection of aquatic life and human uses have been developed in United States, Australia, Canada, Europe and many other places.

The water quality of the re-flooded marshes is an important aspect that helps to evaluate the ecological condition of the marshes and their potential for recovery. In this chapter, I will discuss the main water quality parameters that have been measured in the marshes, and what they indicate about the water quality of the marshes and the ability of the marshes to provide ecosystem services.

3.1.2 Water Quality Assessment

The term water quality assessment (WQA) refers to the evaluation of the overall physical, chemical and biological nature of water in relation to its background level (natural quality), human effects and intended uses (EPA 2002, WHO 2006). Water bodies have the ability to resist or recover from stresses to some degree (Mitsch and Gosselink 2007). However, if stresses are sustained and severe, permanent change can occur (Falk 2006, Mitsch and Gosselink 2007) and ecosystems may not continue to provide the services they provided historically (FDEP 1998). WQA is necessary to determine damage and change to an aquatic environment. It provides critical information to enable the selection of a suitable management plan and the best methods to reduce impacts and damage (CCME 2001, EPA 2002, WHO 2006, Clewell and Aronson 2007, Haines-Young and Potschin 2009).

Scientists usually use standard methodologies for WQA that are time and cost efficient, but sensitive enough to detect changes in the affected environment (Sargent and Carter 1999, EPA 2002, Falk 2006, Clewell and Aronson 2007). Researchers who develop assessment programs may use several methods to determine the ability of a damaged system to recover and maintain a healthy condition (FDEP 1998). These methods usually test the response of the aquatic system to stress and to the removal of stressors (Sedeño-Díaz and López-López 2007, Aloui and Gueddari 2009). However, choosing the best method to assess water quality is difficult and varies from system to system due to differences in the stressors, their degree of impact, and their duration (WHO 2004). Early WQA studies focused on describing the interaction between different water quality parameters and certain biological aspects of the environment (Horton 1965, Brown et al. 1970). Such methods are considered adequate to integrate and interpret an overall picture of the water quality to the public and decision makers (Boyacioglu 2010). Recent WQA studies have developed more complex methods such as indices that combine parameters, not only to assess water quality but also to evaluate the ecological functioning of the system (Davies 2006).

3.1.3 Water Quality Index

A water quality index (WQI) is used to measure the condition of water in comparison to the requirements of one or more aquatic species or for any human need or purpose (WHO 2006). The concept of a WQI is based on the comparison of WQPs with respective regulatory standards; the output is a numerical value that corresponds to a categorical description of the water quality (Davies 2006). The index method was proposed initially by Horton (1965). Since then, the formulation and use of indices has been strongly advocated by agencies responsible for water supply and control of water pollution. The value of such indices is that they summarize detailed water quality information as a single value. Modified WQIs have been widely used to examine the overall condition of water sources according to their use (drinking water, agriculture irrigation, or maintenance aquatic life) at a certain locations and times. According to the UNEP (2007), of eight indices examined (Table 3–1), the CWQI is the most widely used globally.

Table 3–1: Water Quality Indices; modified from Carr and Rickwood (2008).

Index	Objective	Method	Usage
Scatterscore Index	Water quality	Assesses increases or decreases in parameters over time and/or space	USA
Wellbeing of Nations	Human and Ecosystem	Assesses human indices against ecosystem indices	Global
Environmental Performance Index	Environmental health and ecosystem vitality	Uses proximity-to-target measures for 25 performance indicators tracked in six policy categories and combined into a final index score	Global
Index of River Water Quality	River health	Uses multiplicative aggregate function of standardized scores for water quality parameters	Taiwan
Overall Index of Pollution	River health	Assessment and classification of water quality parameters by comparing observations against Indian standards and/or other accepted guidelines e.g. WHO	India
Chemical Water Quality Index	Lake basin	Assesses water quality parameters by standardizing each observation to the maximum concentration for each parameter	USA
National Sanitation Foundation Index	Water quality	Compares water quality of various bodies of water	Global
Oregon Water Quality Index	Water quality	Assesses water quality of various bodies of water	USA
Canadian Water Quality Index for Freshwater Life	Inland waters	Assesses quality of water against guidelines for freshwater life	Global

WQIs distill expert opinion about water quality. For example, indices from the National Sanitation Foundation and the Oregon WQI are based on the Delphi System, which was designed for a specific region, or specific applications such as wastewater management, irrigation, and potable water (Linstone and Turoff, 1975 in Davies 2006). The Delphi Technique (Linstone and Turoff 1975) was based on deriving of several expert opinions, which are obtained via questionnaires in a repeated manner. Such an approach was developed for specific region and could be hard to apply for assessing aquatic life water quality because of the need to sample many water quality parameters (Davies 2006). WQIs are often used as a tool for identifying immediate water quality problems (Davies 2006). Unlike indices based on the Delphi System, the Canadian WQI (CWQI) is often used to assess aquatic life as well as water quality (Davies 2006, Boyacioglu 2007, Al-Saboonchi et al. 2011). The CWQI is designed to assess average water quality over a specified time period, typically a season or a year.

Following a review of the indices outlined in Table 3–1, I chose the CWQI to describe the surface water quality of the re-flooded marshes using the following rationale:

- Scientific rigor - maximum use of monitoring data: Unlike other indices, the CWQI has the flexibility to use a large number of water parameters and select the guidelines (objectives) that match with the environment being considered.
- Amenable to multiple reporting scales - local, regional and national scales of reporting: Depending on the application and geographical location, the number of parameters and the objective for each parameter can easily be adjusted in the index calculations, whereas other indices are strict with certain objectives and parameters.
- Applies to all beneficial water uses, i.e., it is socio-economically relevant
- Consistent use and interpretation across distributed jurisdictions: The CWQI is designed to fit a wide range of aquatic systems regardless of location or function and has been used by several Iraqi scientists to assess marshes, rivers and reservoirs across Iraq (Moyel 2004, Numan 2008, Al-Saboonchi et al. 1982, Hassan et al. 2011).
- Unlike other indices, CWQI takes under consideration two important environmental aspects: the frequency and severity of adverse conditions. The index calculates the frequency and severity using three factors that are combined to give an overall rating and common water quality descriptors.

3.2 Aim of this Chapter

My main goal in this chapter is to assess the water quality of some re-flooded marshes in Mesopotamia. Understanding the current status of the marshes will enable decision makers to address changes and trends due to desiccation and other stressors and will help establish a better and more comprehensive water management plan.

In this chapter I address the following questions:

- What is the overall water quality status of some Mesopotamian marshes after re-flooding and how does it compare to their historical status?
- What are the main WQP affecting the current quality of the Mesopotamian marshes?
- How are the marshes classified according to their significant WQPs?

In order to answer these questions I will:

  - Calculate the WQI scores using the CWQI based on the Turkish Water Pollution Control Regulation (TWPCR) guidelines for selected re-flooded marshes in Al-Hawizeh, Central and Al-Hammar marshes and compare them with the historical WQI scores of the marshes before desiccation.
  - Determine which WQPs have changed.
  - Classify the marshes according to their water quality.

3.3 Materials and Methods

3.3.1 Sampling Sites

Thirteen re-flooded marshes within Al-Hawizeh, Central and Al-Hammar marshes were monitored intermittently from 2004 to 2008 (Table 3–2) to obtain basic water quality data (Table 3–2, Figure 3–1). Marshes were chosen based on three factors: (1) having sufficient water supply during the study period; (2) being ecologically representative of the marsh ecosystem (Dugan 2005); and 3) being safe from a security point of view.

Table 3–2: Water Quality Monitoring Locations. Status refers to the hydrological condition of the selected marshes during the desiccation period.

Location	Status	Water Source	General description
Al-Hawizeh Marshes			
Al-Udhaim	Never dried	Direct water input from Tigris River	Shallow open water with high vegetation cover
Al-Souda north	Semi-dried	Water flows from Al-Udhaim marsh	Shallow open water with slight vegetation cover
Um Al-Niaaj	Semi-dried	Two direct water inputs from Tigris River	Deep open water with high vegetation cover, partially influenced by agricultural activities
Um Al-Warid	Completely dried	Direct water input from Tigris River	Deep open water with high vegetation cover, highly influenced by agricultural activities
Al-Souda south	Completely dried	Water flows from surrounding marshes	Shallow marsh with high vegetation cover
Al-Baydha	Completely dried	Water flows from surrounding marshes	Shallow open water with seasonal-slight vegetation cover
Lissan Ijerda	Completely dried	Water flows from surrounding marshes	Shallow marsh with seasonal-slight vegetation cover
Majnoon	Completely dried	Water flow from surrounding marshes	Shallow marsh with seasonal-slight vegetation cover
Central Marshes			
Abu Zarag	Completely dried	Direct water input from Tigris River	Shallow open water with high vegetation cover, partially influenced by agricultural activities
Al-Baghdadia	Completely dried	Water flows from the surrounding marshes	Deep open water with seasonal-slight vegetation cover
Al-Hammar Marshes			
Al-Kirmashia	Completely dried	Direct water input from Euphrates River	Shallow marsh with seasonal-high vegetation cover
Al-Burka	Completely dried	Water flows from the surrounding marshes	Deep open water with seasonal-slight vegetation cover
Al-Naggara	Completely dried	Water flows from the surrounding marshes	Shallow marsh with seasonal-high vegetation cover

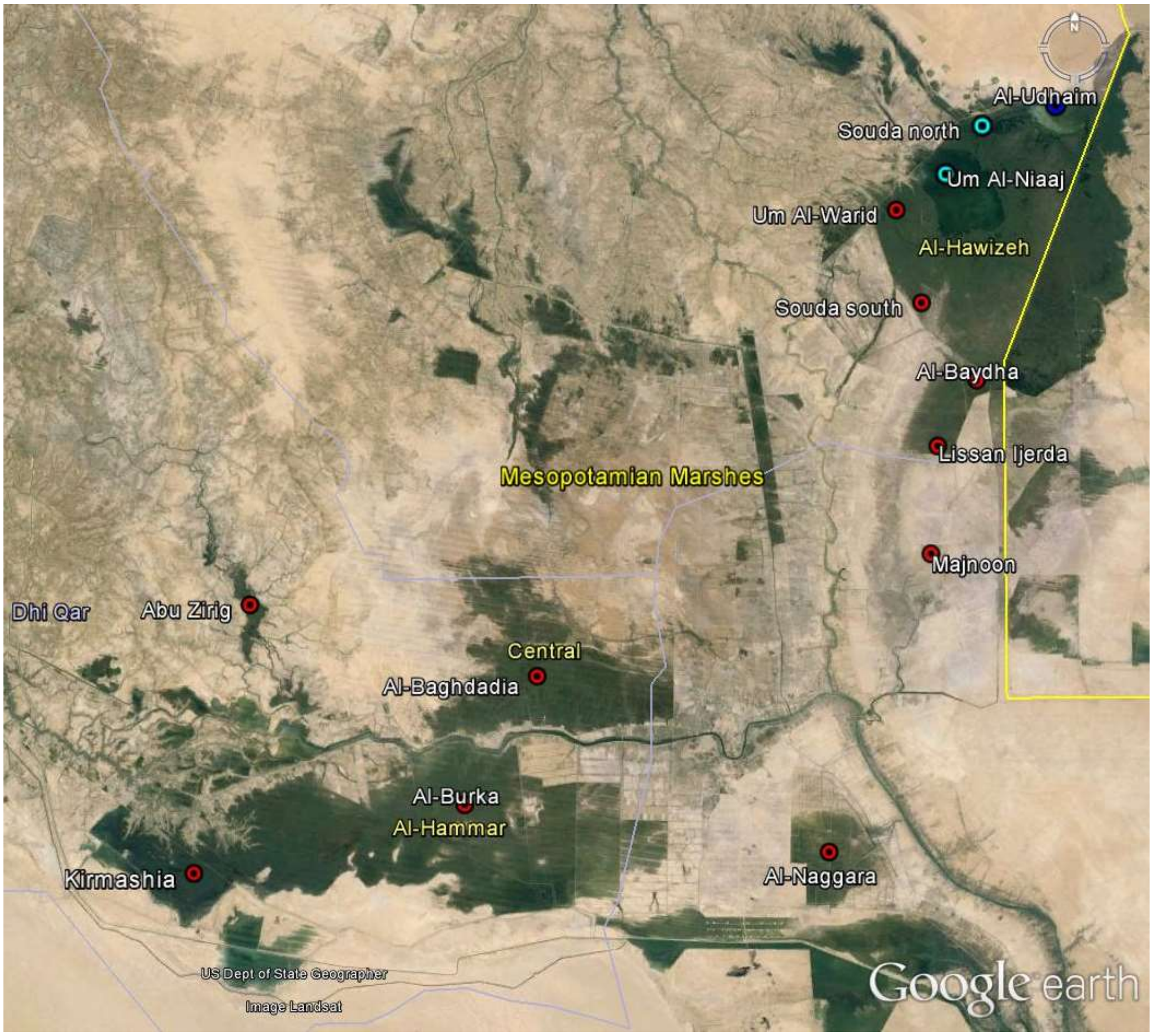


Figure 3–1: Water Quality Monitoring Locations Source: U.S. Department of State Geographer). Never dried (dark blue), partially dried (light blue), and completely dried (red).

3.3.2 Data Sources

Data from 2004 to 2008 for selected WQPs including WCD, light penetration (LP), pH, DO, nitrate (NO_3^-), soluble reactive phosphate (SRP), Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}, TDS, salinity, total suspended solids (TSS), and biological oxygen demand (BOD) were monitored from 2005 to 2008 (refer to Table A1 in Appendix 1). These parameters were chosen for the assessment process because they were most regularly measured. Water quality data from 1978 – 1979 were taken from Maulood et al. (1979) and water quality data from 1983-1985 were taken from Al-Zubaidi (1985) and Al-Lami (1986).

3.3.3 Field Monitoring

WQP including water temperature, salinity, DO and pH were measured *in situ* using a WTW Multi-meter model 350i. Water samples were collected in triplicate from 0.3 m below the water surface using a horizontal Van Dorn sampler. The dissolved nutrients analysed included NO_3^- and SRP and the major ions analysed were Mg^{2+}, Ca^{2+}, SO_4^{2-} and Cl^-. Water samples were filtered immediately in the field using pre-weighed Whatman GF/F 0.7-μm pore-size filters except for water samples collected during the Mesopotamian Marshes Recovery Assessment (MRA) survey, which were filtered through Whatman GF/C 1.2-μm pore-size filters. The filtrate (500 ml) was transferred into translucent polyethylene screw-cap plastic bottles after the bottles were pre-rinsed twice with the filtrate. Filters used for TSS measurements were individually stored in petri dishes at 4°C until analysis.

3.3.4 Laboratory Methods and Analyses

The standard methods described by Stainton et al. (1977) were used to determine NO_3^- and SRP. The major ions, BOD and TDS were determined according to the standard procedures described in APHA (2005). TSS was determined according to the gravimetric method as described in Stainton et al. (1977).

3.3.5 Data Analysis

3.3.5.1 Water Quality Index (WQI)

I used the CWQI to describe the surface water quality of the re-flooded marshes during the period 1983 to 2008 as in the example below (CCME 2001):

Table of Example Data: Values that failed their respective guideline (objective) are bolded.

Sampling period	**Cl^-**	**TDS**	**BOD**	**NO_3^-**
May	20	**1000**	3.1	3.1
June	19	**900**	2.2	2
July	10	**800**	1.1	5.1
August	**30**	**800**		**15**
September	**100**	320	3.9	**40**
Guideline	*<25 mg/L*	*<500 mg/L*	*<4 mg/L*	*<5 mg/L*

There are three factors that combined to calculate the CWQI; F1 (Scope), F2 (Frequency) and F3 (Amplitude). The example has four variables (Cl^-, TDS, BOD, and NO_3^-) and a total of 19 values (4 for BOD and five for Cl^-, TDS, and NO_3^-).

The measure for scope (F_1) represents the extent of non-compliance over the time period of interest:

$$F_1 = \left[\frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables}\right] \times 100$$

$$= \left[\frac{3}{4}\right] \times 100 = 75.0$$

The measure for frequency (F_2) represents the percentage of individual tests that do not meet objectives (failed tests):

$$F_2 = \left[\frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests}\right] \times 100$$

$$= \left[\frac{8}{19}\right] \times 100 = 42.1$$

The measure of amplitude (F_3) represents the amount by which failed test values do not meet their objectives. When an individual concentration is greater than (or less than, when the objective is a minimum) the objective is termed an "excursion" and is expressed as follows:

- When the test value must not exceed the objective:

$$excursion_{\mathrm{i}} = \left[\frac{Failed\ test\ value}{Objective_j}\right] - 1$$

- When the test value must not fall below the objective:

$$excursion_{\mathrm{i}} = \left[\frac{Objective_j}{Failed\ test\ value}\right] - 1$$

The collective amount by which individual tests are out of compliance (*nse*) is calculated as:

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{Number\ of\ tests}$$

$$nse = \left(\frac{\left(\frac{30}{25} - 1\right) + \left(\frac{100}{25} - 1\right) + \left(\frac{1000}{500} - 1\right) + \left(\frac{900}{500} - 1\right) + \left(\frac{800}{500} - 1\right) + \left(\frac{800}{500} - 1\right) + \left(\frac{15}{5} - 1\right) + \left(\frac{40}{5} - 1\right)}{19}\right)$$

$$\mathrm{nse} = 0.8$$

Then F_3 can calculate as:

$$F_3 = \left[\frac{nse}{0.01nse + 0.01}\right]$$

$$F_3 = \left[\frac{0.8}{0.01 \times 0.8 + 0.01}\right] = 64.01$$

The WQI is then calculated as:

$$WQI = 100 - \left[\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right]$$

$$WQI = 100 - \left(\frac{\sqrt{75^2 + 42.1^2 + 64.01^2}}{1.732}\right) = 100 - 2.8 = 97.2$$

The F_1, F_2, and F_3 are combined to produce a single value ranging between 0 and 100 that describes water quality (0 indicates the poorest and 100 indicates the best water quality). Within this range, values may be defined to classify water quality as poor, marginal, fair, good or excellent.

I used the TWPCR guidelines (Table 3–3) because: (1) their standards have a similar categorization scheme to European legislation (Boyacioglu 2010); and (2) these guidelines are comprehensive, using more than 45 water quality variables without specifying usage.

Table 3–3: WQP and guidelines values (TWPCR, 2008) of the Mesopotamian marshes. Values are in mg/L except pH.

Category	WQP	Guidelines
General	pH	>6 or <9
	DO	>6
	BOD	<5
Dissolved Solids and Major Ions	TDS	<700
	SO_4^{-2}	<500
	Cl	<100
Nutrients	NO_3^-	<1

The CWQI categorization scheme proposes five quality classes (excellent, good, fair, marginal and poor). Since the TWPCR guidelines that I used in this study classify waters into four categories, I used a fit-for-purpose modified categorization scheme by Boyacioglu (2010). In my study, an index score less than 35 is defined as Class IV waters. Therefore Table 3–4 was organised using index scores representing four quality classes.

Table 3–4: Modified CWQI categorization scheme.

Water Quality Class	Index Score	Remark
Class I High Quality	95-100	High potential to be used as drinking water supply, trout production and other purposes
Class II Moderate Quality	55-94	Potential to be used as drinking water supply, fish production (except trout)
Class III Polluted	35-54	Process water supply for some industries
Class IV Highly Polluted	0-34	Should be treated before use

WQIs were calculated using pH, DO, NO_3^-, TDS, BOD, SO_4^{2-}, and Cl^- when available. Based on the availability of these data, the CWQI was calculated as three different indices. Index 1 included pH, DO, and NO_3^-, index 2 included pH, DO, NO_3^-, TDS, and BOD, and index 3 included all seven parameters (pH, DO, NO_3^-, TDS, BOD, SO_4^{2-}, and Cl^-).

3.3.5.2 Temporal Differences

I chose Wilcoxon signed ranks tests to investigate differences in WQPs including pH, DO, salinity, NO_3^-, and SRP between the period before desiccation (1970s and 1980s) and after re-flooding (2005 to 2008). This test was chosen as these data failed tests of normality.

3.3.5.1 Marsh Classification

I used cluster analysis and principal components analysis (PCA) to illustrate similarities between the selected re-flooded marshes in terms of their water quality and compare them to the marsh that had never been dried (Al-Udhaim). Data on WCD, LP, pH, DO, TSS, salinity, Ca^-, Mg^{2+}, SO_4^{2-}, Cl^-, NO_3^-, SRP, TDS, and BOD, from 2004 to 2008, were standardized prior to these analyses (McGarial et al 2000) because the variables do not have the same unit of measurement. The cluster analysis was done by means of Ward’s method, using squared Euclidean distances. I used the package FactoMineR for both the PCA and the cluster analysis.

3.4 Results

3.4.1 Water Quality Status of the Marshes

Descriptive statistics of WQP observed from 1978 to 1979, from 1983 to 1985 and from 2004 to 2008 are listed in Appendix 2 Table B1.

Generally, water quality of the re-flooded marshes according to index 1, calculated based on pH, DO, and NO_3^-, were moderate with WQI scores ranging from 75 to 55, except for Al-Souda south marsh in Al-Hawizeh that was ranked as polluted with a WQI score of 53.6 (Table 3–5; Figure 3–2). The inclusion of TDS and BOD parameters in the WQI (index 2) lowered the WQI scores of Al-Burka marsh (Al-Hammar), Um Al-Niaaj, Um Al-Warid, and Al-Souda south (Al-Hawizeh) below 55; thus their water quality was also ranked as polluted (Table 3–5; Figure 3–2). The inclusion of Cl^- and SO_4^{2-} in the WQIs of the re-flooded marshes (index 3) lowered the water quality index scores of all the marshes even more. The water quality of the Central and Al-Hammar marshes ranked as highly polluted with WQI scores below 35 and Al-Hawizeh marsh was ranked as polluted with WQI scores below 55 (Table 3–5; Figure 3–2).

Table 3–5: WQI scores referenced to CCME.

Marsh	Period		WQI	Water Quality Class
Al-Hammar marshes				
Al-Burka	1985	Index 1	74.6	Moderate
	2005 – 2008	Index 1	74.6	Moderate
		Index 2	50.9	Polluted
		Index 3	**29.5**	**Highly polluted**
Al-Kirmashia	2004 – 2008	Index 1	66.6	Moderate
Al-Nagara	2006 – 2007	Index 2	74.3	Moderate
		Index 3	**33.1**	**Highly polluted**
Al-Hawizeh marshes				
Majnoon	1983 – 1984	Index 1	65.4	Moderate
	2006 – 2008	Index 1	75.0	Moderate
		Index 2	64.4	Moderate
Al-Udhaim	2005 – 2008	Index 1	73.9	Moderate
		Index 2	65.5	Moderate
Um Al-Niaaj	2005 – 2008	Index 1	75.7	Moderate
		Index 2	54.5	Polluted
		Index 3	35.5	Polluted
Lissan Ijerda	2005 – 2008	Index 1	77.4	Moderate
		Index 2	57.7	Moderate
Um Al-Warid	2005 – 2008	Index 1	78.5	Moderate
		Index 2	50.2	Polluted
		Index 3	37.1	Polluted
Al-Souda north	2006 – 2008	Index 1	72.0	Moderate
		Index 2	63.7	Moderate
Al-Baydha	2006-2008	Index 1	73.4	Moderate
		Index 2	65.2	Moderate
Al-Souda South	2006-2008	Index 1	53.6	Polluted
		Index 2	50.8	Polluted
Central marshes				
Al-Baghdadia	1983 – 1984	Index 1	67.5	Moderate
	2005 – 2008	Index 1	66.3	Moderate
		Index 2	56.3	Moderate
		Index 3	**33.0**	**Highly polluted**
Abu Zarag	2004 – 2005	Index 1	64.6	Moderate

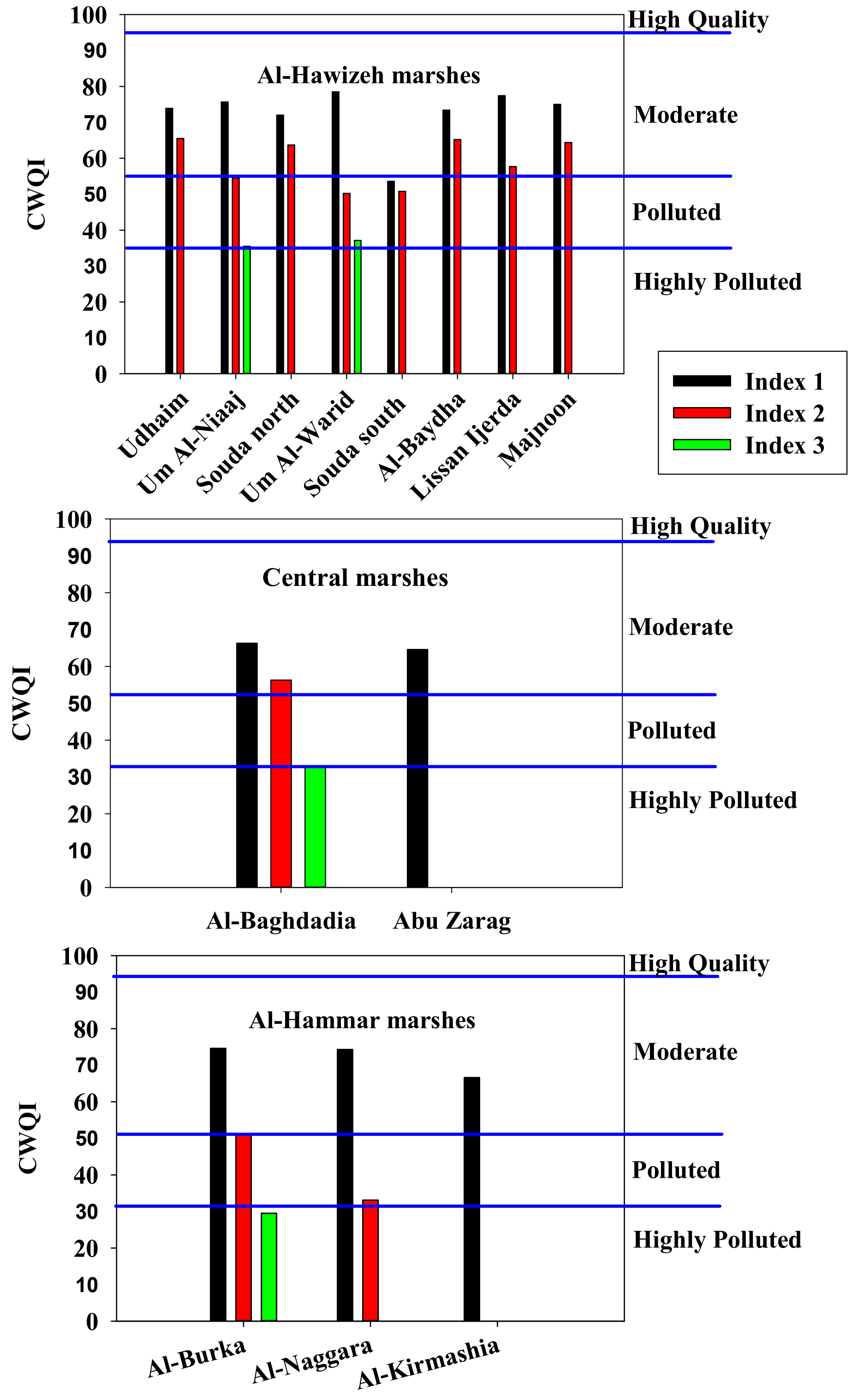


Figure 3–2: Water quality index values for sites within Al-Hawizeh, Central, and Al-Hammar marshes during 2005 to 2008.

Among the selected WQP that I used to assess to calculate the WQIs of the marshes after inundation, DO concentrations in Al-Baghdadia, Al-Kirmashia, and Al-Souda south marshes were lower than the guideline value for the TWPCR, while BOD concentrations in Al-Baghdadia and Al-Souda south marshes were higher than the guideline value for the TWPCR (Figure 3–3). TDS and Cl^- concentrations were over the guidelines values for the TWPCR, while SO_4^{-2} concentrations in Al-Hawizeh marshes were within the acceptable level for the TWPCR except in Al-Souda south marsh (Figure 3–3).

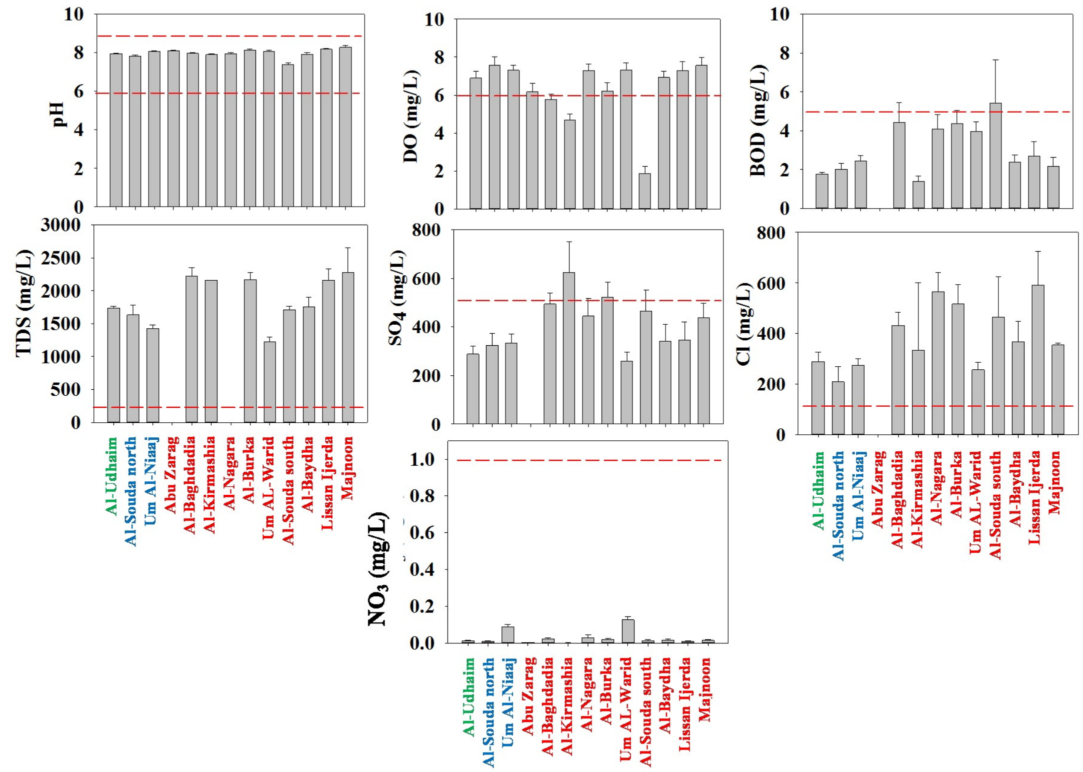


Figure 3–3: Average concentration of the selected WQP at the Mesopotamian marshes (never dried marsh in green, semi dried marshes in blue, completely dried marshes in red) from 2004 to 2008. Dashed horizontal lines represent the guidelines values for the TWPCR (see Table 3–3). Error bars are standard error.

Temporal differences in the Al-Hammar (Al-Burka), the Al-Hawizeh (Majnoon) and the Central marshes (Al-Baghdadia) between their historical status before desiccation (1983 – 1985) and after desiccation (2004 – 2008) were also investigated. Due to data availability, WQIs of these marshes were calculated using Index 1. The water quality in the three marshes was similar before and after desiccation and was classified as moderate during both periods (Table 3–5, Figure 3–4).

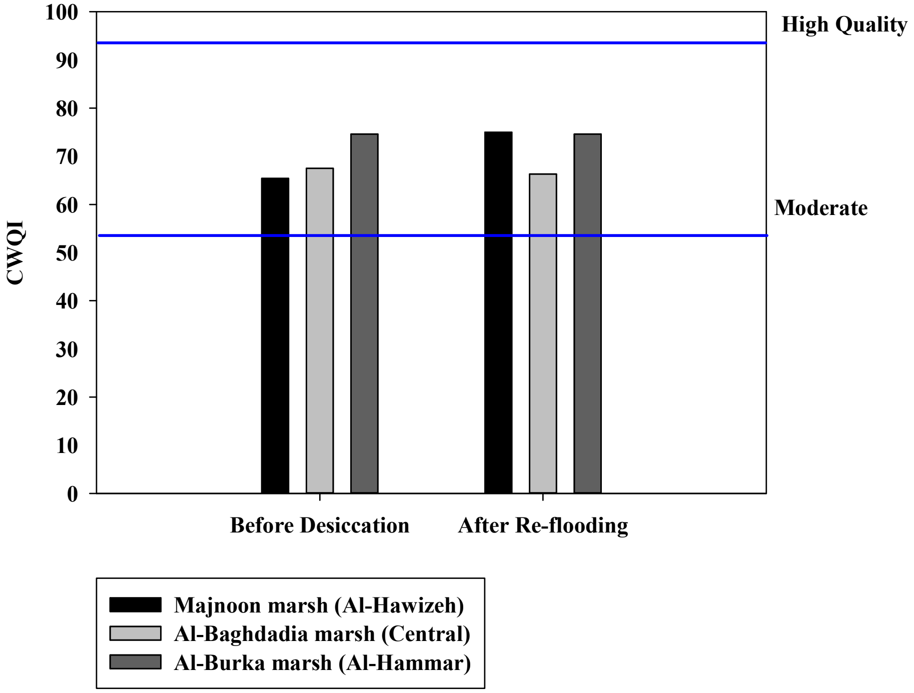


Figure 3–4: Water quality index values for the selected marshes in Al-Hawizeh, Central, and Al-Hammar before desiccation and after re-flooding.

Mean differences between selected WQP (salinity, pH, DO, NO_3^- and SRP) before and after re-flooding for Mesopotamian marshes are listed in Table 3–6.

Table 3–6: Comparison between selected WQP before and after re-flooding for marshes within the Al-Hammar, Central, and Al-Hawizeh marshes.

	Before				**After**			
	Mean	**Range**	**Min**	**Max**	**Mean**	**Range**	**Min**	**Max**
Al-Baghdadia marsh*								
pH	7.7	1.1	7.1	8.2	8	2.4	6.5	8.9
DO	4.9	0.8	4.5	5.3	5.8	14.1	1	15.1
Salinity	0.4	0.5	0.2	0.7	1.5	4.9	0.7	5.6
NO_3^-	38.2	78	3	81	22.6	371.8	0.4	372.2
SRP	13.4	25	1	26	8.3	78.2	0.1	78.3
Al-Burka marsh**								
pH	8.1	1	7.6	8.6	8.1	1.6	7.2	8.8
DO	6.9	11	1	12	6.2	10.9	1	11.9
Salinity	2.5	3	1.3	4.3	2	2.1	1.2	3.3
NO_3^-	1.7	8.9	0.3	9.2	18.9	195.1	0.9	196
SRP	0.4	0.8	0.1	0.9	6	42.7	1.5	44.2
Majnoon marsh***								
pH	8.5	1.2	8	9.2	8.3	2	6.7	8.8
DO	5.7	7.8	1.1	8.9	7.6	10.4	1.3	11.7
Salinity	5.5	3.1	3.4	6.5	1.1	0.4	0.9	1.3
NO_3^-	1.6	3	0.4	3.4	14.5	51.2	0.4	51.6
SRP	0.7	1.7	0.2	1.9	4.7	5	2.1	7.2

*data from 1978-1979 vs. data from 2005-2007)

**data from 1985 vs. data from 2005-2008)

***data from 1983-1984 vs. data from 2006-2008)

Salinity, pH, DO, NO_3^- and SRP were used to investigate temporal differences between the 1970s and 2000s using Wilcoxon signed ranks test. The result shows that there is no significantly temporal different ($p > 0.05$) in pH level, DO, and salinity in Al-Hammar marsh. Salinity was different ($p < 0.05$) in Central and Al-Hawizeh marshes. In Al-Baghdadia marsh (Central), salinity increased after re-flooding relative to the historical value while salinity in Majnoon marsh (Al-Hawizeh) decreased (Table 3–6). There were significant temporal differences ($p < 0.05$) in NO_3^- and SRP among the marshes. NO_3^- and SRP in Al-Burka marsh (Al-Hammar) and Majnoon marsh (Al-Hawizeh) increased after re-flooding relative to their historical value, while In Al-Baghdadia SRP concentrations decreased after re-flooding.

3.4.2 Marsh Classification

The PCA ordination of the sites illustrates that the sites from the three marshes are distinct in their water quality (Figure 3–5). The first principal component captured 40% of the variance while the second principal component captured 25%.

The grouping of the marshes on the PCA is similar to that produced by the cluster analysis (Figure 3–6). Um Al-Warid and Um Al-Niaaj marshes (Al-Hawizeh) grouped together and they have high concentrations of DO, NO_3^-, and SRP and low concentrations of BOD, Ca^{+2},SO_4^{-2}, Cl^-, and TSS. Al-Hammar, Central, and Lissan Ijerda and Majnoon marshes of Al-Hawizeh grouped together as their water tend to have high salinity and TSS concentrations. The rest of the Al-Hawizeh marshes, including Al-Udhaim, Al-Souda north and south and Al-Baydha, are grouped together as their water quality have low salinity and TSS concentrations and deep water with good LP.

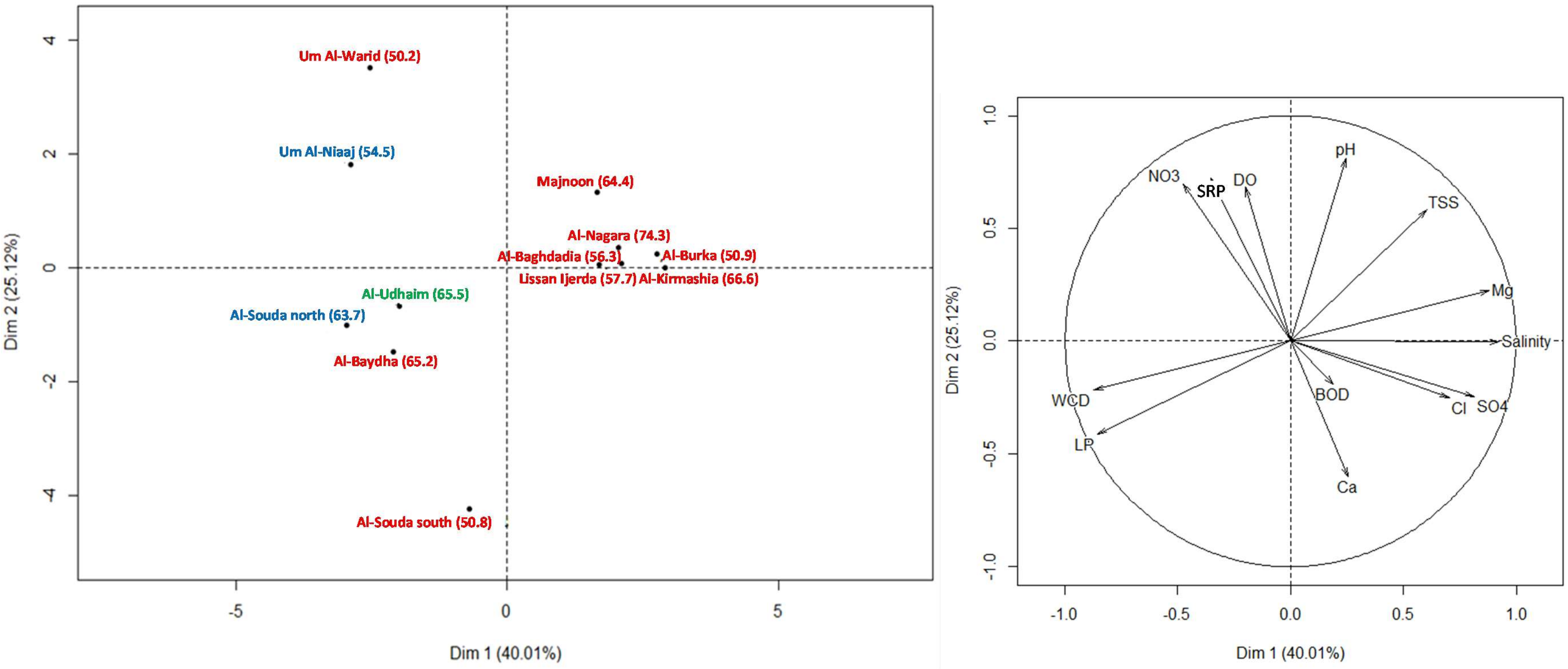


Figure 3–5: Principal components ordination of the marshes (left) and the relationship of the original variables to the first two principal components. The green label is the never dried marsh; the blue labels include semi – dried marshes, and the red labels for completely dried marshes. WQI scores are in brackets.

Table 3–7: Correlation matrix of the water quality variables from which the principal components were extracted. Bold numbers indicate significant correlation ($p < 0.05$).

	WCD	**LP**	**pH**	**DO**	**TSS**	**Salinity**	**Ca^{+2}**	**Mg^{+2}**	**SO_4^{-2}**	**Cl^-**	**NO_3^-**	**SRP**	**BOD**
WCD	1.00												
LP	**0.82**	1.00											
pH	-0.53	-0.52	1.00										
DO	-0.03	-0.06	**0.75**	1.00									
TSS	-0.58	**-0.85**	0.55	0.16	1.00								
Salinity	**-0.72**	**-0.72**	0.18	-0.09	0.48	1.00							
Ca^{+2}	-0.25	-0.01	-0.20	-0.38	0.03	0.08	1.00						
Mg^{+2}	**-0.76**	**-0.82**	0.26	-0.15	0.56	**0.87**	-0.17	1.00					
SO_4^{-2}	-0.52	**-0.63**	-0.14	-0.55	0.39	**0.76**	0.23	**0.79**	1.00				
Cl^-	**-0.60**	-0.39	0.02	-0.22	0.18	**0.73**	0.32	0.49	0.40	1.00			
NO_3^-	0.32	0.13	0.27	0.28	0.13	-0.45	-0.68	-0.18	-0.50	-0.36	1.00		
SRP	0.19	0.02	0.30	0.19	0.29	-0.35	-0.56	-0.05	-0.31	-0.42	**0.92**	1.00	
BOD	-0.05	-0.06	-0.33	-0.47	-0.11	0.19	-0.22	0.28	0.17	0.51	0.21	0.02	1.00

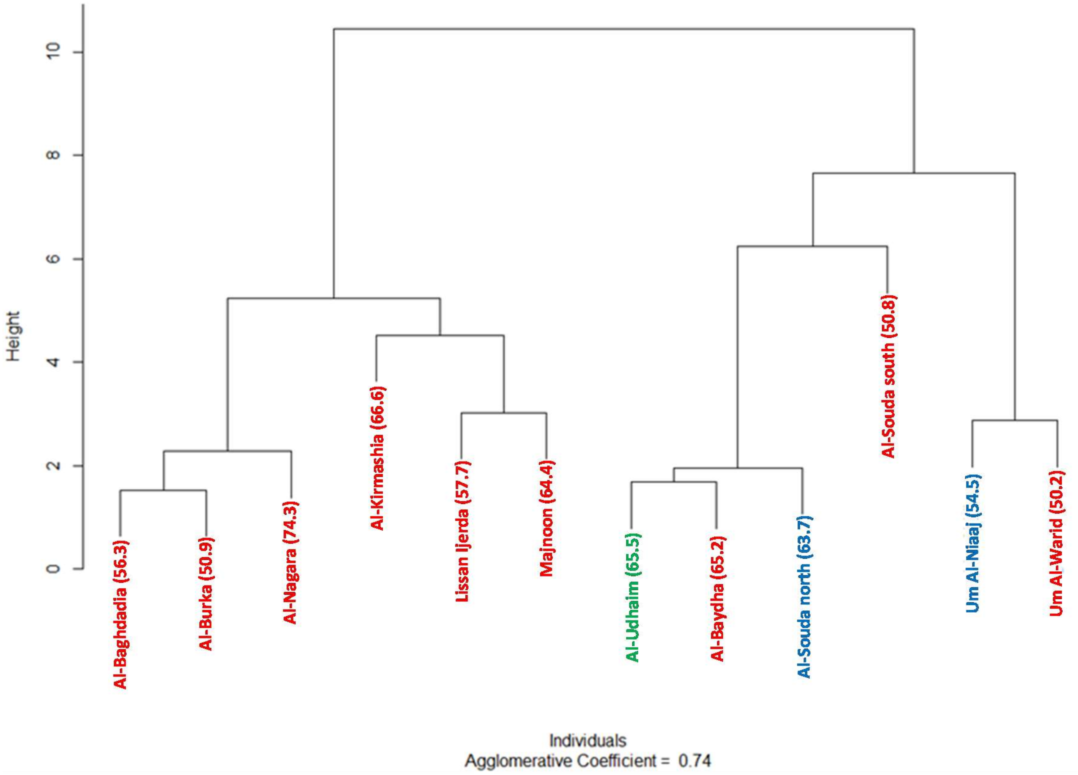


Figure 3–6: Dendrogram illustrating the similarities among marshes based onWard's method. The green label is the never dried marsh; the blue labels include semi – dried marshes, and the red labels for completely dried marshes. WQI scores are in brackets.

3.5 Discussion

3.5.1 Water Quality Status of Mesopotamian marshes

The CWQI clarify that the water quality status of some Mesopotamian marshes after re-flooding is “polluted” (Figure 3–2) according the criteria used by the TWPCR (2008), which agrees with the few studies that investigate the water quality of the re-flooded marshes (Al-Saboonchi et al. 2011). The deterioration in the marshes’ water quality is mainly due to the hydrological changes of the water sources, desiccation processes, and increase agriculture discharge. In addition, the diminished spring surge after re-flooding compared to the natural hydrological cycle (see Figure 2–6 in Chapter 2) affects the fluctuation of physical and chemical parameters annually (Mitsch and Gosselink 2007).

The WQI based on pH, DO, and NO_3 suggests that the water quality of re-flooded marshes was moderate both before and after re-flooding. This does not mean that the WQP have not changed, as will be discussed below. Most WQA studies of the Mesopotamian marshes (Richardson and Hussain 2006, Al-Saboonchi et al. 2011, Warner et al. 2011) found differences in water quality between the two periods; however, these studies were describing the general condition of the marshes and included variables related to salinity.

3.5.2 WQP affecting the current quality of the Mesopotamian marshes

Designation of the water quality of the re-flooded marshes as “moderate” depends on low DO concentration in some marshes that historically were dried. Low DO concentrations in these marshes can be a reflection of high decomposition and/or high chemical redox reactions due to organic matter deposition during the desiccation period, especially early in inundation. The deterioration in of the water quality of the re-flooded marshes from moderate to polluted, especially in the completed dried marshes, is due to the inclusion of TDS that increased significantly after re-flooding (see Chapter 2). BOD also was a reason for some of the completely dried marshes being designated as “polluted” that are far from water inputs and tend to be stagnant, while BOD concentrations in the large open water marshes where water is well oxygenated are within the acceptable level for TWPCR. The significant decline in the water quality of the re-flooded marshes was related to the inclusion of Cl to the WQI. This also related to the significant increase in salinity within the marshes over time and especially after inundation as described in Chapter 2.

3.5.3 Changes of the WQP of the Mesopotamian Marshes Overtime

I evaluated changes for some water quality parameters before and after the desiccation period. In contrast to the lack of change in DO and pH, there was an increase in NO_3^-, especially in Al-Hammar (Al-Burka marsh) and the Central marshes (Al-Baghdadia marsh) after desiccation.

However, salinity increased over time, especially in the Central and Al-Hammar marshes (Table 3–6). This is related to the increased salinity of the Euphrates, and possibly the impact of salt deposition during the desiccation period (refer to Chapter 2). In case of Al-Hawizeh, the reason why the salinity after re-flooding was lower than the pre-desiccation level could be because the salinity of Majnoon marsh in 1985 was very high due to the impact of agriculture input at that time (Hussain 1994). Although, Al-Hawizeh marshes shows a significant reduction in salinity after re-flooding (section 2.5.3) still their average salinity (0.8 psu) is higher that the historical level (see Table 1–2).

Although NO_3^- and SRP were significantly ($p < 0.05$) increased after re-flooding relative to their historical values (see Table 1–2) in Al-Hammar and Al-Hawizeh marshes, their increase did not exceed the acceptable concentrations (10 mg/L for NO_3^- and 0.01 mg/L for SRP) for aquatic life reported by Canadian Council of Ministers of the Environment (CCME 2004) The increase in NO_3^- and SRP could be related to: 1) mineralization of organic matter accumulated during the desiccation period (Cole 1983, Mitsch and Gosselink 2007); 2) the location of the marshes (Al-Burka in Al-Hammar marsh and Majnoon in Al-Hawizeh) close to agriculture inputs (Mahamed 2008, Mosier et al. 2004); or 3) lack of vegetation cover, especially during early inundation period (Craft et al. 2002) and therefore low microbial removal of phosphorus from soil or water (Walbridge and Stuthers 1993). SRP concentrations in Central marsh were lower after re-flooding than their historical values. This is could be because the marsh I sampled, Al-Baghdadia, is far from the water input that is likely the main source of phosphorus and contains high vegetation cover that increases phosphorus removal from water via plants (Craft et al. 2002) and high microbial removal of phosphorus from soil or water (Walters and Johnson 2007).

3.5.4 Marshes Classification

PCA analysis and cluster analysis based on water quality parameters grouped the marsh sites similarly, and different from the general classification described in Mahamed (2008) and listed in Table 3–2. Mahamed (2008) classified the sites based on their hydrological status. Based WQPs, the marshes can be considered as three groups: marshes with high nutrients and DO concentrations, marshes with high salinity, and deeper marshes with low salinity.

Generally, the classification analyses revealed that the water quality characteristics of the Central and the Al-Hammar marshes were generally similar and different from north part of Al-Hawizeh marshes. This is mainly due to the differences in water inputs; Central and Al-Hammar marshes are mostly fed by Euphrates tributaries, although the Abu Zarag marsh in the eastern part of the Central marshes receives water input from the Tigris via the Al-Gharaf, while Al-Hawizeh marshes have water inputs mostly from the Tigris River. Al-Hawizeh marshes have fresher water overall, but the areas of Al-Hawizeh that completely dried (Al-Baydha, Souda South, Majnoon, and Lissan Ijerda) had moderate salinity compared to the never dried Al-Udhaim marsh and the semi-dried marshes Souda North and Um Al-Niaaj. The significant differences in salinity among the Al-Hawizeh marshes are mostly related to the differences in the hydrological status during the desiccation period and increases in salinity due to evaporation that moves from north to south as described in Chapter 2.

Chapter 4 Biological Assessment: Re-flooded Al-Hawizeh Marsh Case Study

4.1 Introduction

4.1.1 Biological Assessment

Efforts to restore the marshes since 2003 have had some success (Richardson et al. 2005, Mahamed 2008, Warner et al. 2011). One of the most important aspects of assessing the ecological recovery of wetlands is to measure their biological communities. Although physical and chemical water quality parameter scan provide quantitative information on the status of a wetland, they may not reflect the environmental stress on organisms or the effects of this stress (Omar 2010). In order to protect biological resources, scientists should be able to predict and identify problems, impacts, and stressors that significantly affect the biological community.

Biological assessment (BA) has been used widely during the last 30 years to determine the condition of aquatic resources and track changes in ecosystems (Willen 2000, Imteaz et al. 2003, Soler-López et al. 2005). A BA can estimate the degree of environmental impact based on the response of specific organisms to environmental changes (Willen 2000). Some species used in BA are referred to as biological indicators, whose occurrence or absence reflects environmental conditions (Kovacs 1992). Biological indicators can detect the impact of different stressors, including physical, chemical and biological changes (Mitsch and Gosselink 2007). Stressors can change the abundance of aquatic organisms either negatively, because some organisms cannot tolerate the changes, or positively, because other organisms may tolerate or even benefit from the changes (Nielsen et al. 2003).

4.1.2 Phytoplankton as Indicators to the Health of Aquatic Systems

Phytoplankton have been used to classify waters since the late 19th century (Willen 2000) and, although they have been well-studied in oceans and lakes, they are also among the most ecologically important groups of aquatic organisms in marshes (Mitsch and Gosselink 2007). Furthermore, these organisms have been used as indicators to monitor the health and recovery of damaged ecosystems (Maasdam and Claassen 1998, Bianchi et al. 2003, Imteaz et al. 2003, Sigareva and Lyashenko 2004, Fathi and Flower 2005, Kumari et al. 2008). Phytoplankton have short generation times and can respond rapidly to a number of environmental changes (Lek et al. 2005). As a result, they usually demonstrate strong seasonal cycles (Imteaz et al. 2003, Sommer et al. 2012) that need to be considered in their use as indicators. Furthermore, they exhibit high biodiversity, play a major role in energy flow and nutrient cycling, and are affected by physical and chemical stressors including pollutants (Table 4–1). In addition, shifts in phytoplankton species composition in response to anthropogenic stresses can be used to predict effects on other ecosystem components (McCormick and Cairns 1994).

The types of phytoplankton present in the algal community can indicate water quality (good, moderate, bad) and be used to classify different types of water including those affected by pollutants (Kolkwitz and Marsson 1908, Teiling 1955, Palmer 1969). For examples, increase the abundant of species like *Oscillatoria tenuis* C.Agardh ex Gomont, *Botryococcus braunii* Kützing, and *Fragilaria capucina* Desmazières would decreas the water quality and indicate of pollution (Table 4–1). Genum such as *Melosira* and *Cocconeis* can be a reflection to changes in the physical charstristic of the water (**Error! Reference source not found.**). Some diatoms such as *Achnanthes minutissima* Kützing, *Coscinodiscus antiquus* Schütt, *Fragilaria capucina* Desmazières, *Gomphonema acuminatum* Ehrenberg, and *Surirella linearis* W.Smith is an indication of good quality water that contains acceptable level of nutrients, is well oxygenated, and is transparent (Omar 2010, Venkatachalapathy and Karthikeyan 2013, Yang, et al. 2014).

Table 4–1 Examples of phytoplankton species indicative of different physical and chemical stressors (Modified from Kelly et al. (1990).

Factor	**Response**	**Indicator phytoplankton taxa**
Current speed	Sluggish currents favour loosely-attached filaments	*Melosira* sp.
	Fast currents favour	*Cocconeis* sp.
Grazing pressure	Resistant to grazing	*Cocconeis placentula* Ehrenberg
	Produces toxins	*Oscillatoria tenuis* C.Agardh ex Gomont, *Microcystis aeruginosa* (Kützing) Kützing, *Amphora ovalis* (Kützing) Kützing
Pollution	Capable of heterotrophic growth	*Nitzschia palea* (Kützing) W.Smith, *Scendesmus* sp.
	Oil pollution	*Botryococcus braunii* Kützing, *Duniella tertiolacta* Butcher
	Organic matter	*Chlorella* sp.
Heavy metals	Have morphological aberrations in the presence of heavy metals	*Fragilaria capucina* Desmazières
	Can develop tolerance to high level of metals	*Achnanthidium minutissimum* (Kützing) Czarnecki
Eutrophication	Has a competitive advantage at low nutrient concentrations	*Eunotia* sp., *Dolichospermum* sp.
	Grows well at high nutrient concentrations	*Diatoma vulgara* Bory de Saint-Vincent
Salinity	Characteristic of brackish conditions	*Diploneis pseudovalis* Hustedt, *Melosira nummuloides* C.Agardh, *Coscinodiscus lacustris* Grunow
pH	Growth favoured by low pH	*Eunotia exigua* (Brébisson ex Kützing) Rabenhorst
Temperature	Competitive advantage at low temperature	*Navicula lanceolata* Ehrenberg, *Navicula gregaria* Donkin

Water quality parameters may interact to determine the success of the phytoplankton species. For example, the response of phytoplankton to a nutrient may be affected by the levels of other nutrients. The net effect is that phytoplankton communities respond to their environment by changing their structure (composition, abundance and biomass) and function (photosynthesis, respiration). High phytoplankton densities or "blooms" often indicate poor water quality and environmental health (Bellinger and Sigee 2010). Different phytoplankton groups, such as Cyanobacteria, have the ability to produce toxins and other noxious chemicals that increase can have potential impacts on drinking and recreational waters (Dokulil 2003, Bellinger and Sigee 2010). Species of cyanobacteria such as *Microcystis*, produce a variety of toxins, including microcystins and toxins, that can affect animals and humans (Medupin 2011). Others including *Dolichospermum* sp. and *Aphanizomenon* sp., can also produce harmful toxins that can cause serious contamination of water drinking that can harm humans and cause poisoning (Imai et al. 2008). Blooms of *Botryococcus braunii* Kützing of class Trebouxiophyceae are able to produce harmful fatty acids that can be toxic to other micro-organisms and fish (Chiang and Huang 2004).

World wide, increasing nutient concentrations in aquatic systems is a big concern as they can cause serious ecological problems by enhancing harmful phytoplankton growth (Xu, et al. 2014). Cyanobacterial blooms are frequently associated with increase phosphorus concentration in aquatic system (Smith et al. 1999) because some Cyanobacteria have the ability to fix atmosphiric nitrogen (N_2) via prosess called nitrogen-fixation. Generally, nitrogen availability and cycling play an important role in forming cyanobacterial communities because declining nitrogen has been shown to select for N fixers, where subsequent nitrogen from N_2 fixation could stimulate toxic cyanobacterial growth (Beversdorf et al. 2013). There are two groups of nitrogen-fixing Cyanobacteria: 1) those that can fix N_2 aerobically, mostly heterocystous genera, e.g., *Dolichospermum* but also non-heterocystous genera, e.g., *Gloeothece*, *Cyanothece*, *Trichodesmium*, *Katagnymene*, *Lyngbya*; and 2) Cyanobacteria that fix N_2 only anaerobically or microaerobically. These include non-heterocystous Cyanobacteria like *Plectonemaboryanum* (Issa et al. 2014).

Phytoplankton, especially diatoms, have been widely used as a tool to investigate the changes and detect for shifting in aquatic systems over time (Wetzel 2001). Diatoms, one group among the algae, are characterized by being enclosed in frustules made of silica. The hydrated silicon dioxide component of the frustule protects the organism and persists even after the death of the cell. For that reason, diatoms are a popular tool for monitoring past and present environmental conditions (Smol and Stoermer 1999) and are commonly used in studies of water quality (Blinn and Bailey 2001). Diatoms collectively show a broad range of tolerance along gradients of aquatic productivity and other environmental dimensions, but their species composition changes in a rapid and diagnostic manner to perturbation while providing a record in the sediment (Round et al. 1990, Dixit et al. 1992, Cooper 1995, Hobson and McQuoid 2001). Diatoms are primarily photoautotrophic organisms and are directly affected by changes in nutrients and light (Leira et al. 2009), but they have been calibrated against many other aspects of their environment (Nielse et al. 2003, Blinn et al. 2004). Besides using diatoms as a tool to investigate the changes and detect for shifting in aquatic systems over time, a few diatom species produce toxins that affect human and animal health. For example, the genera *Pseudo-nitzschia* and *Amphora* can produce toxic domoic acid and a neurotoxin (domoic acid) that are harmful to molluscs, birds, mammals, and humans (Dhar et al. 2015).

Phytoplankton response to environmental conditions can be detected by changes in species composition, cell density, biomass, chlorophyll, or enzyme activity (e.g., alkaline phosphatase). These characteristics may be used, singly or in aggregate, to assess conditions with respect to societal values, such as aesthetics, likely presence of toxins, biological integrity, and trophic condition. Omer (2010) summarises the algal attributes and indicators that are used in biological monitoring programs not just including harmful algae but also phytoplankton that can be used as indicator for good water quality.

Biological indices have been developed and modified to measure condition, diagnose the type of stressor, define management approaches to protect and restore biological conditions, and evaluate performance of protection (Patrick 1949, EPA 2002). For example, the United States Environmental Protection Agency has developed the Index of Biological Integrity, which is a simple and direct method that combines several biological indicators (vascular plants, amphibians, birds, algae, macroinvertebrates). The IBI method uses quantitative measurements (e.g., taxa richness, biomass, or abundance) that show clear changes in value along a gradient of influence. Alternatively, multivariate analyses that examine the relationship between biological communities and environmental data have been used to assess water quality (Sabater et al. 1988, Hill et al. 2000, Winter and Duthie 2000). Redundancy analyses and principal response curves are multivariate techniques that have been used to examine differences in species composition between affected and control systems. Van den Brink et al. (1999) proposed the principal response curve (PRC) technique, which is a multivariate method based on redundancy analysis and is similar to PCA. This method is sensitive to changes in community response over time in comparison to a control system. This allows the method to illustrate time-dependent treatment effects. The response of the impacted community or communities relative to the control is plotted against time, yielding a PRC of the community for each treatment. What is special about this analysis is that the PRC method illustrates time-dependent, community-level effects of stress in a graphical form that can be more readily interpreted than other ordination techniques.

4.2 Aim of this Chapter

In this chapter, phytoplankton assemblages were examined to understand the nature and extent of recovery of the Al-Hawizeh marshes. One part of these marshes (Al-Udhaim) was never drained and is used as a reference. I used the phytoplankton data collected during the Nutrient Budget (NB) survey (May 2006 to January 2007; refer to Table A1 in Appendix 1) in eight sub-marshes in Al-Hawizeh to ask the following questions:

- Are there differences in species abundance and diversity in phytoplankton communities among the marshes?
- What environmental parameters relate to the observed differences in phytoplankton communities?

This will be accomplished through the following:

  - Comparison of abundance and richness of phytoplankton species in marshes with different hydrological histories in Al-Hawizeh (completely dried, semi-dried, and never dried).
  - Application of the PRC method to analyse changes in the phytoplankton community and environmental parameters over the sampling period (2006 – 2008) using the never-dried Al-Udhaim marsh as a reference site.

4.3 Materials and Methods

4.3.1 Sampling Sites

Eight sub-marshes in Al-Hawizeh marsh complex were grouped based on their hydrological status: group 1 includes only Al-Udhaim marsh, which had standing water throughout the desiccation period (never dried); group 2 includes the Um Al-Niaaj and Al-Souda north marshes, which shrunk in size but never completely dried (partially dried); and group 3 includes the Al-Souda south, Al-Baydha, Lissan Ijerda, and Majnoon marshes, which were completely dried.

A general description of these marshes is presented in Table 3–2 and locations of the marshes are depicted in Figure 3–1. GPS coordinates of the selected marshes are listed in Table A2 in Appendix 1.

4.3.2 Data sources

Data were collected through the NB survey during May 2006 to January 2007 and from the CIMI II survey in February and August of 2008 (Table A1 in Appendix 1). Water quality and phytoplankton data are available from both surveys. Chlorophyll *a* (chl *a*) data are available only for the NB survey.

4.3.3 Field Monitoring

Quantitative phytoplankton samples were collected using a horizontal Van Dorn water sampler. 1 L samples were transferred to polyethylene containers and fixed with 10% Lugol's Iodine solution. Methods for collecting the physical data and samples for chemical analysis are outlined in Section 3.3.3. Samples for chl*a* determination (1 L) were filtered immediately in the field using pre-weighed Whatman GF/F 0.7 µm pore-size filters. The filters were preserved by adding 5 ml of 1% magnesium chloride and then were frozen for no longer than 24 h.

4.3.4 Laboratory Methods and Analyses

The laboratory methods used to determine NO_3^-, SRP and TSS concentrations are presented in Section 3.4.4. SiO_2 was measured as recommended byStrickland and Parsons (1968). Chl *a* was measured according to the monochromatric method described in Lorenzen (1967). Extraction occurred in the dark at -4 °C over night. The next day, the supernatants were allowed to reach room temperature and then transferred to1 cm quartz cells and measured in a Shimadzu spectrophotometer at 750 nm and 655 nm. The absorbance at 750 nm was used to correct the chlorophyll absorbance for turbidity.

Quantitative samples of phytoplankton were concentrated to 10 ml by settling and then siphoning off the supernatant, and prepared for identification according to the procedure described in Patrick & Reimer (1975). For diatom identification, a drop of preserved material was placed on a clean cover slip, dried and cleaned with hot concentrated nitric acid, followed by use of the micro transect method for counting. A haemocytometer method was used for other phytoplankton species identification. The concentrated samples were identified and enumerated using an Olympus CH2 microscope. Diatom species identification was based on keys in Patrick & Reimer (1975) and Hustedt (1985). Other phytoplankton species were identified according to keys in Desikachary (1959) and Prescott (1978). However, I used Guiry and Guiry (2015) to determine correct and current taxonomic nomenclature.

4.3.5 Data Analysis

Diversity is the measure of both species richness and evenness. Species richness (R) is the total number of species per sample. Species evenness (E) is a measure of the relative abundance of the different species. I the calculated Shannon-Wiener Index (H; Odum 1969) in order to investigate the differences in phytoplankton diversity among the selected stations as described below:

$$H = \sum (P_i \times Ln(P_i))$$

Where P_i is the proportion of total sample represented by species i.

Also, I calculated evenness (Smith and Wilson 1996) based on species richness variation (E_{var}) to understand the nature of the differences between the marshes. It is used to estimate how evenly distributed resources are between species or taxa in a given location. E_{var} index is calculated as:

$$E_{var} = 1 - 2 \Big/ \pi \arctan\left\{\sum_{R=1}^{R}(\ln(x_R) - \sum_{t=1}^{R} ln(x_t\,)/R)^2/R\right\}$$

> Where x is species abundance; π refers to Pi, which is equal to 3.142; and arctan is the function that returns the arctangent of a number in radians, in the range –π/2 to π/2.

I chose the Wilcoxon rank test to investigate differences in phytoplankton species between sub marshes in Al-Hawizeh and between the three marsh classes of Al-Hawizeh, never dried, semi dried and completely dried. This test was chosen as these data failed tests of normality.

Redundancy analysis (RDA) of phytoplankton communities and environmental variables was calculated with CANOCO for Windows 4.5 (Ter Braak and Šmilauer 2002). Environmental data were log-transformed, and effectively centred and standardized by basing the analysis on the correlation matrix. The statistical significance of each derived environmental axis was assessed using a Monte Carlo unrestricted permutation test involving 499 permutations. The tri-plot ordinates sites according to their predicted species composition, show the centroids of the species distributions, and illustrate the environmental variables as arrows (Ter Braak 1987).

The PRC method was used to illustrate the composition of the phytoplankton communities of the 7 drained or partially drained marshes relative to the never dried marsh, Al-Udhaim, and the relationship of the differences to the environmental parameters SRP, nitrite (NO_2^-), NO_3^-, SiO_2, salinity, pH, water temperature, DO, and WCD over the sampling period from April 2006 to April 2007 and February 2008. Species data and environmental parameters were log–transformed, except pH values. Environmental parameters were centred and standardized by basing the analysis on the correlation matrix.

4.4 Results

Eight phyla of phytoplankton including; Bacillariophyta, Charophyta, Chlorophyta, Cyanobacteria, Cryptophyta, Euglenozoa, Ochrophyta, and Miozoa were recorded and a total of 269 species distributed among fourteen classes were identified during the study period (April 2006 to January 2007, February 2008 and August 2008; Table 4–2). Data on composition and abundance in the Al-Hawizeh marshes are listed in Table C1 in Appendix 3. The monthly abundance of the identified phytoplankton classes is listed in Table C2 in Appendix 3.

Table 4–2: Taxonomic groups identified in the Al-Hawizeh marshes during the study period.

Phylum	Class	N. of species	Total abundance During the study period (Cells/ml)
Cyanobacteria	**Cyanophyceae**	35	55634
Charophyta	**Zygnematophyceaee**	15	8379
Chlorophyta	**Chlorophyceae**	34	69989
	Trebouxiophyceae	12	16713
	Ulvophyceae	3	3
Ochrophyta	**Xanthophyceae**	3	264
	Chrysophyceae	2	348
Euglenozoa	**Euglenophyceae**	7	1957
Miozoa	**Dinophyceae**	2	5424
Cryptophyta	**Cryptophyceae**	1	11530
Bacillarophyta	**Coscinodiscophyceae**	4	289
	Bacillarophyceae	127	57390
	Mediophyceae	9	26682
	Fragilariophyceae	14	5202
	Total	**269**	**259805**

During the study period, Class Bacillariophyceae contributed the most species and was most abundant in the Al-Hawizeh marshes followed by class Chlorophyceae (Table 4–2). Classes Ulvophyceae and Xanthophyceae was recorded but were very rare, <5 cells/ml and <300 cells/ml, respectively.

Majority of the identified phytoplankton (84%) during the study period were freshwater species. However, there were several brackish species including *Navicula cryptocephala var. veneta* (Kützing) Rabenhorst, *Diploneis pseudovalis* Hustedt, Fallacia pygmaea (Kützing) A.J.Stickle & D.G.Mann, *Halamphora coffeiformis* (C.Agardh) Levkov, and *Mastogloia braunii* Grunow; some ubiquitous species including; *Geitlerinema amphibium* (C.Agardh ex Gomont), *Anagnostidis Merismopedia elegans* A.Braun ex Kützing, *Caloneis bacillum* (Grunow) Cleve, and *Oscillatoria subbrevis*

Schmidle; and some fresh/terrestrial species including: *Achnanthes minutissima* Kützing, *Ankistrodesmus falcatus* (Corda) Ralfs, *Cylindrospermum stagnale* Bornet & Flahault, and *Navicula radiosa* Kützing. Several euryhaline species were present in high abundant (between 300 cells/ml to 3000 cells/ml) including *Merismopedia glauca* (Ehrenberg) Kützing, *Cocconeis placentula* Ehrenberg, *Haslea spicula* (Hickie) L.Bukhtiyarova, and *Nitzschia acicularis* (Kützing) W.Smith.

Several harmful phytoplankton species that produce toxins were observed. The harmful species include *Microcystis aeruginosa* (Kützing) Kützing, *Oscillatoria curviceps* C.Agardh ex Gomont, *Oscillatoria tenuis* C.Agardh ex Gomont, and *Snowella lacustris* (Chodat) Komárek & Hindák that belong to class Cyanophyceae; *Peridinium cinctum* (O.F.Müller) Ehrenberg that belong to class Dinophyceae; *Botryococcus braunii* Kützing that belong to calss Trebouxiophyceae; and *Amphora ovalis* (Kützing) Kützing and *Nitzschia sigmoidea* (Nitzsch) W.Smith belong to class Bacillarophyceae.

4.4.1 Species Richness, Abundance and Diversity

Phytoplankton richness and abundance varied among the sampling stations (Figure 4–1). During the study period, the highest species count (richness) and abundance were 162 species and 1,113,234 cell/ml, respectively, recorded in Majnoon marsh, while the lowest species count and abundant were 106 species and 5,602 cell/ml, respectively, recorded in Al-Baydha marsh (Table 4–3).

During the study period, class Bacillarophyce contributed the most species richness, but class Chlorophyceae were most abundant except at Majnoon marsh, where class Baccillariophycea were most abundant (Table 4–3, Figure 4–1). Percentage of Class Chlorophyceae abundance among the marshes ranged from 16% recorded in Majnoon marsh to 38% recorded in Um Al-Niaaj marsh. Also the results indicate high abundance of class Cyanophyceae, especially in marshes located south Al-Hawizeh. In Majnoon, Al-Souda south, and Lissan Ijerda, class Cyanophyceae contributed 33%, 29%, and 24% of the total classes abundance, respectively, whereas its abundance in the northern marshes of Al-Hawizeh was low and did not exceed 13%. Generally, class Coleochaetophyceae and class

Ulvophyceae had the lowest percentage of abundance (<0.5%). Abundant percentage of class Chrysophyceae also was low, <0.5%, especially in the southern marshes of Al-Hawizeh.

Table 4–3: Phytoplankton abundance (cells/ml) and species richness (in brackets) for dominant taxonomic classes in the Al-Hawizeh marshes from April 2006 to January 2007.

	Al-Udhaim	**Um Al-Niaaj**	**Al-Souda north**	**Um Al-Warid**	**Al-Souda south**	**Al-Baydha**	**Lissan Ijerda**	**Majnoon**
Cyanophyceae	1484 (20)	1382 (18)	1625 (18)	2436 (12)	1948 (14)	600 (16)	8542 (17)	37617 (26)
Zygnematophyceaee	3889 (12)	57 (6)	3670 (9)	9 (1)	28 (5)	10 (5)	225 (8)	493 (7)
Chlorophyceae	4994 (19)	11513 (20)	4026 (17)	13543 (13)	2129 (14)	1849 (10)	13515 (18)	18421 (19)
Trebouxiophyceae	149 (8)	364 (6)	166 (5)	4700 (7)	27 (1)	0	3378 (9)	7929 (6)
Ulvophyceae	0	2 (1)	0	0	<0.5 (1)	<0.5 (2)	0	0
Xanthophyceae	86 (1)	23 (1)	55 (1)	<0.5 (1)	36 (1)	18 (1)	0	46 (2)
Chrysophyceae	92 (2)	38 (2)	218 (2)	<0.5 (1)	<0.5 (1)	<0.5 (1)	<0.5 (1)	0
Euglenophyceae	358 (3)	240 (2)	181 (1)	172 (4)	263 (6)	91 (3)	508 (6)	126 (5)
Dinophyceae	351 (3)	595 (3)	489 (3)	1082 (3)	308 (3)	326 (2)	797 (3)	1412 (3)
Cryptophyceae	2466 (1)	1634 (1)	634 (1)	236 (1)	199 (1)	371 (1)	2612 (1)	3379 (1)
Coscinodiscophyceae	11 (2)	20 (3)	<0.5 (2)	112 (3)	56 (2)	23 (3)	11 (2)	56 (3)
Bacillarophyceae	2150 (53)	2713 (67)	1912 (50)	4677 (67)	1245 (52)	1534 (49)	4074 (54)	39073 (75)
Mediophyceae	448 (7)	10873 (6)	264 (4)	10624 (7)	301 (5)	290 (5)	1826 (7)	1997 (8)
Fragilariophyceae	373 (11)	843 (6)	255 (8)	202 (10)	190 (8)	491 (8)	279 (7)	2687 (7)
Total	**16851 (142)**	**30297 (142)**	**13494 (121)**	**37793 (130)**	**6731 (114)**	**5602 (106)**	**35766 (133)**	**113234 (162)**

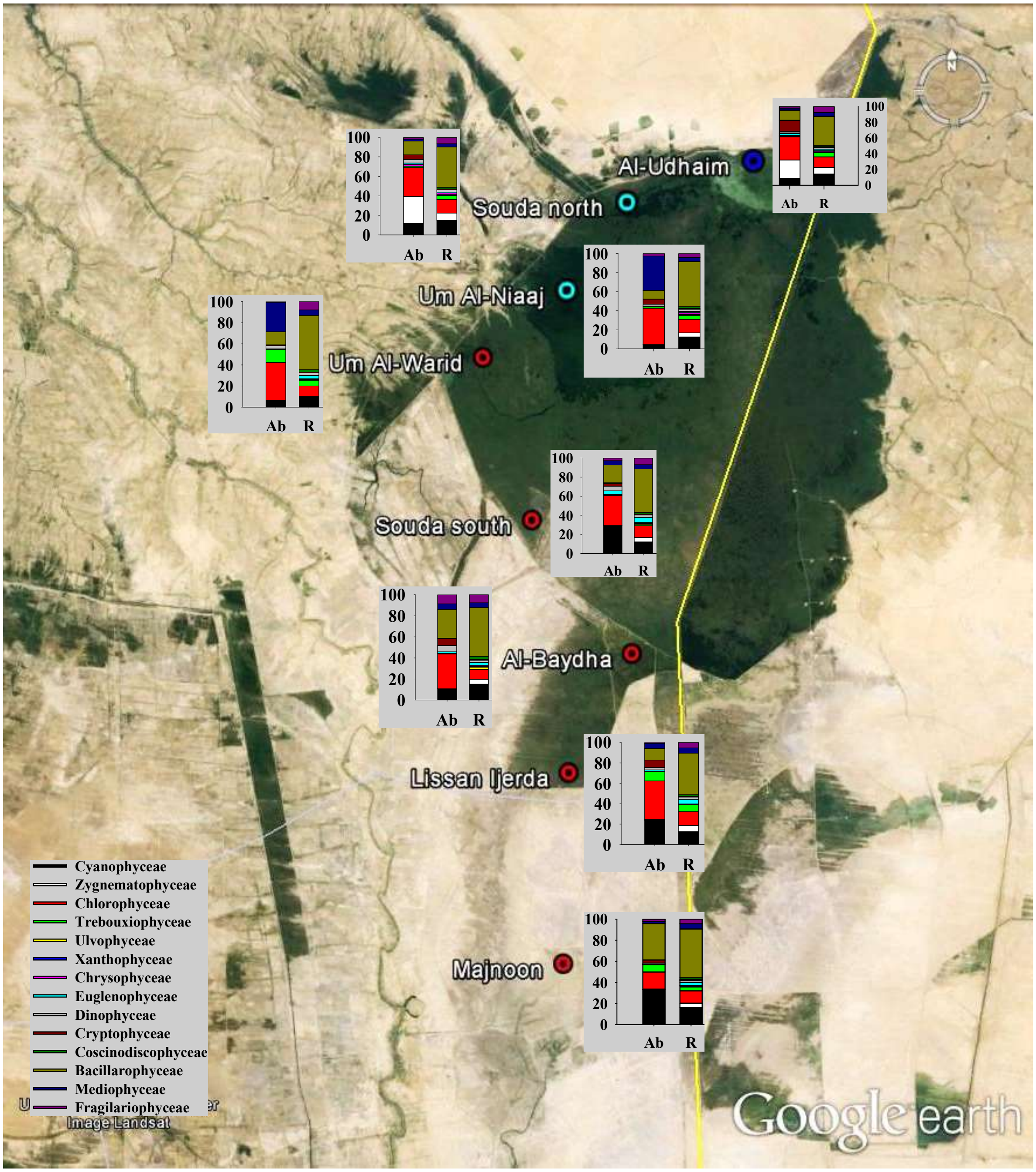


Figure 4–1: Composition (Ab) and species richness (R) as percent of the total for identified phytoplankton classes in Al-Hawizeh marshes during the study period.

Wilcoxon rank tests indicate that there are differences in species abundance between the marshes within Al-Hawizeh (p<0.05; Table 4–4). The Wilcoxon rank test found no differences in species abundance between the never dried marsh and the semi dried marshes; however, it did show differences between the never dried marsh and completely dried marshes, except for Um Al-Warid.

Table 4–4: Wilcoxon rank test of species abundance (blue numbers) between the selected marshes of Al-Hawizeh during the study period. **Bold** numbers indicate significant differences (α=0.05) between marshes.

	Al-Udhaim	**Um Al-Niaaj**	**Al-Souda north**	**Um Al-Warid**	**Al-Souda south**	**Al-Baydha**	**Lissan Ijerda**	**Majnoon**
Al-Udhaim*	1.000							
Um Al-Niaaj	0.097	1.000						
Al-Souda north	0.110	**0.000**	1.000					
Um Al-Warid	0.927	0.183	0.129	1.000				
Al-Souda south	**0.000**	**0.000**	**0.001**	**0.000**	1.000			
Al-Baydha	**0.000**	**0.000**	**0.006**	**0.002**	0.385	1.000		
Lissan Ijerda	**0.002**	0.094	**0.000**	0.156	**0.000**	**0.000**	1.000	
Majnoon	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	1.000

*The green marsh is the never dried marsh, the blue are the semi – dried marshes, and the red are the completely dried marshes.

Phytoplankton diversity in Al-Hawizeh marshes was investigated using both Shannon Wiener and Evenness (E_{var}) indices (Figure 4–2). The results showed that Al-Udhaim and Lissan Ijerda marshes had high diversity of phytoplankton among the monitored marshes of Al-Hawizeh during the study period, while Um Al-Warid marsh was the least diverse (Figure 4–2). Evenness (E_{var}) index ranged from 0.61 to 0.74.

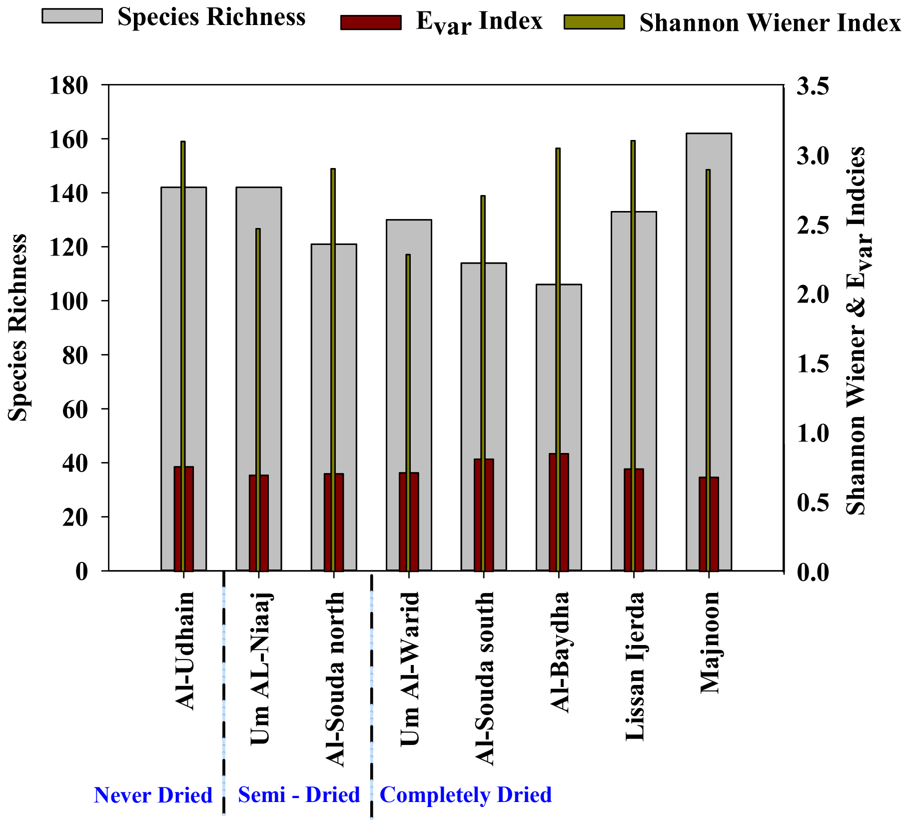


Figure 4–2: Species Richness, Shannon Wiener Diversity and Evenness (E_{var}) in the Al-Hawizeh marshes.

Species richness and abundance varied among the marshes, especially during 2006 (Figure 4–3, Table 4–5). The minimum number of phytoplankton taxa was 1 species recorded in Al-Souda north marsh in July 2006, while the maximum was to 70 species recorded in Um Al-Niaaj marsh in August 2006. Al-Udhaim, Um Al-Niaaj and Majnoon marshes generally had the highest species richness during the study period, although Majnoon appeared to generally decrease over the study period. Al-Souda south and Al-Baydha marshes had the lowest species richness during the study period.

The total abundance of phytoplankton differed and was not synchronous among the marshes during the study period (Figure 4–3). Several marshes had highest abundance in spring (April and May), while some marshes had highest abundance in late summer (August and September). Um Al Niaaj had highest abundance in winter (February). Um Al-Niaaj, Um Al-Warid and Majnoon marshes generally had the highest cell counts during the study period, exceeding 10000 cells/ml (Figure 4–3, Table 4–5). Al-Souda north marsh had the lowest abundance of phytoplankton (18 cells/ml) in July 2006. Phytoplankton abundance in Al-Baydha marsh and Al-Souda south was generally low compared to the other marshes (Figure 4–3, Table 4–5).

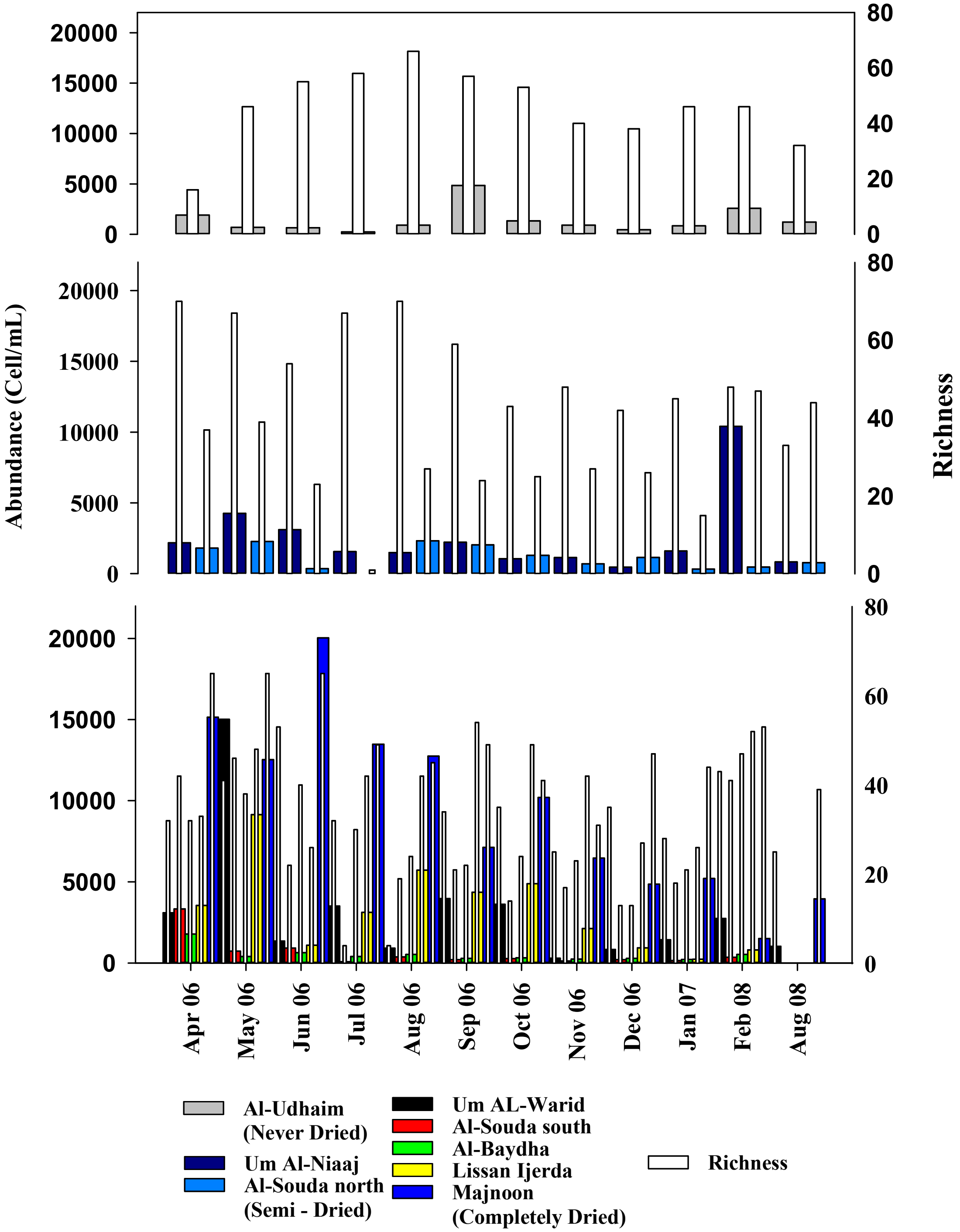


Figure 4–3: Monthly variation of phytoplankton abundance and richness in Al-Hawizeh marshes during the study period.

Table 4–5: Monthly variation of phytoplankton abundance and species richness (in brackets) among the selected marshes of Al-Hawizeh. Abundance unit is cells/mL; ND = no data.

	Al-Udhaim	**Um Al-Niaaj**	**Al-Souda north**	**Um Al-Warid**	**Al-Souda south**	**Al-Baydha**	**Lissan Ijerda**	**Majnoon**
Apr-06	1919 (16)	2179 (70)	1805 (37)	3091 (32)	3328 (42)	1784 (32)	3548 (33)	15141 (65)
May-06	707 (46)	4256 (67)	2267 (39)	15016 (41)	729 (46)	399 (38)	9140 (48)	12527 (65)
Jun-06	656 (55)	3101 (54)	357 (23)	1353 (53)	925 (22)(	632 (40)	1089 (26)	20039 (65)
Jul-06	241 (58)	1564 (67)	18 (1)	3509 (32)	75 (4)	402 (30)	3122 (42)	13479 (49)
Aug-06	926 (66)	1486 (70)	2321 (27)	915 (4)	370 (19)	522 (24)	5722 (42)	12746 (45)
Sep-06	4860 (57)	2220 (59)	2038 (24)	3964 (34)	205 (21)	285 (22)	4357 (54)	7123 (49)
Oct-06	1340 (53)	1055 (43)	1295 (25)	3612 (35)	271 (14)	316 (24)	4886 (49)	10204(41)
Nov-06	912 (40)	1135 (48)	698 (27)	289 (25)	124 (17)	236 (23)	2125 (42)	6459 (31)
Dec-06	461 (38)	462 (42)	1145 (26)	832 (35)	199 (13)	287 (13)	933 (27)	4858 (47)
Jan-07	853 (46)	1605 (45)	320 (15)	1437 (28)	149 (18)	217 (21)	232 (26)	5210 (44)
Feb-08	2583 (46)	10404 (48)	466 (47)	2744 (43)	357 (41)	524 (47)	807 (52)	1504 (53)
Aug-08	1222 (32)	831 (33)	776 (44)	1032 (25)				3944 (39)

4.4.2 Phytoplankton Biomass (Chlorophyll *a*)

Chl*a* in the Al-Hawizeh marsh displayed both seasonal and spatial variation (Figure 4–4). Chl *a* was generally elevated during the summer and early fall and then decreased during winter. Relatively low chl *a* with unremarkable peaks was observed in Al-Baydha, Al- Niaaj and in the undisturbed marsh, Al-Udhaim. The semi-dried marsh, Al-Souda north, had relatively low chl *a* concentration with increased values in late summer. Chl *a* among completely dried marshes showed higher concentrations in the summer with the exception of Majnoon which had the highest concentration and variation with a peak in the fall and Al Baydha which had generally stable and low Chl *a* through the year. With the exception of Al Baydha, chl *a* in the marshes that had been completely dried was higher than in the other marshes.

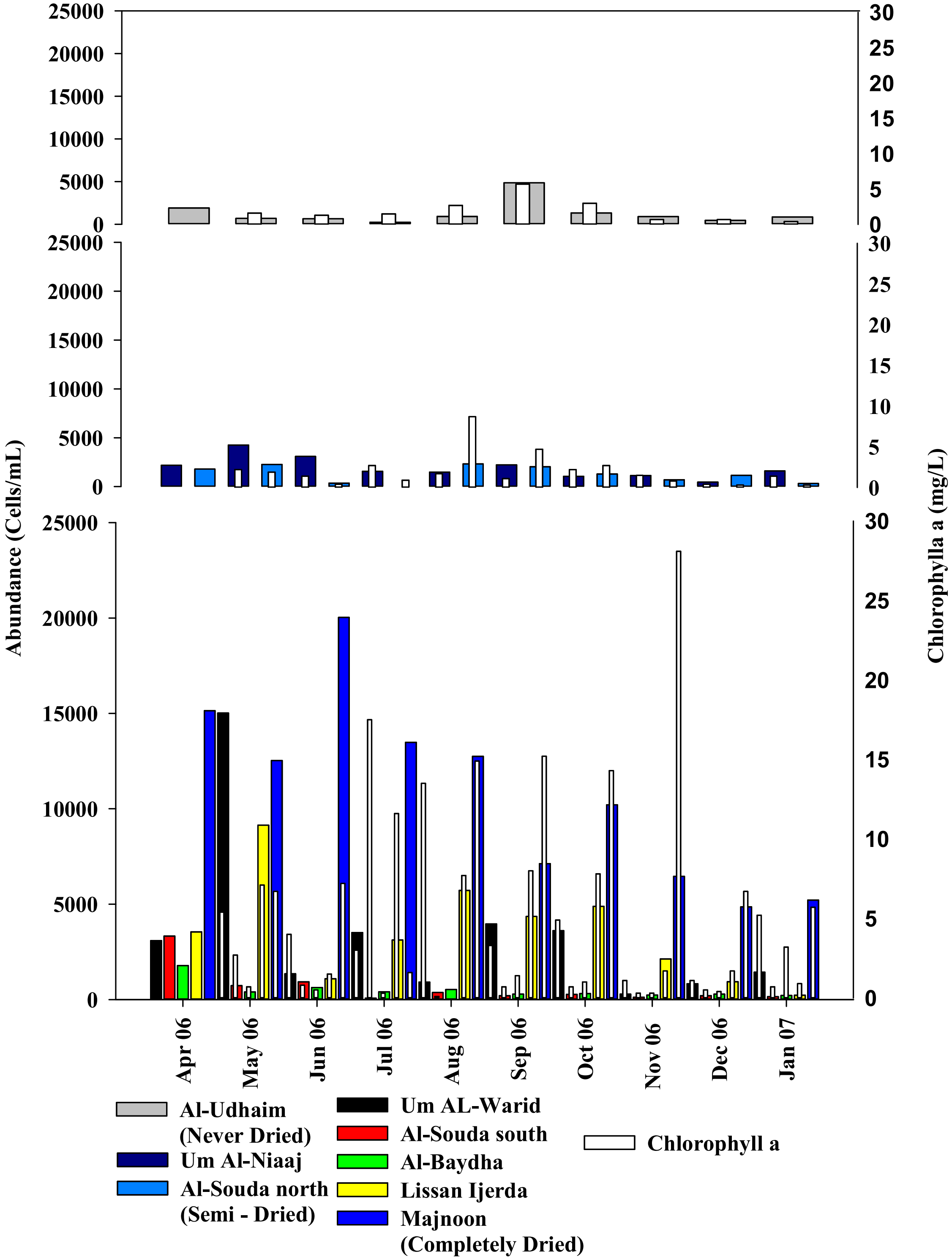


Figure 4–4: Monthly variation of phytoplankton abundance and chlorophyll a (chl a) in Al-Hawizeh marshes during the study period.

4.4.3 Role of Water Quality Parameters on Phytoplankton Distribution

The monthly average of the physical-chemical parameters and nutrients in Al-Hawizeh marshes are listed in Table 4–6. The shape of the underlying distributions for the marshes from April 2006 to April 2007, February 2008 and August 2008 are shown in Figure 4–5.

The average salinity of the never-dried marsh (0.8 psu) and the semi-dried marshes (0.7 psu) were lower than in the completely dried marshes (1.1 psu), except for Um Al-Warid marsh (0.5). Unlike the completely dried marshes, the never-dried marsh and semi-dried marshes had lower salinity values in summer (May to September) than in winter and early spring (October to February). The average DO was highest in the marshes closest to fresh water inputs, especially in Um-Al-Niaaj marsh. In the totally dried marshes (Al-Souda south and Al-Baydha) the range in DO was relatively high. With the exception of Souda south, DO generally exceeded the CCME (1999) minimum criteria for the protection freshwater aquatic life of 5.5 mg/L. The average concentrations of SRP and NO_3 within the three groups of Al-Hawizeh marshes were lower than 5 µg/L and 15µg/L, respectively, except in Um Al-Warid marsh where their average concentrations were 28 µg/L and 32 µg/L, respectively. Average concentration of SiO_2 in the never dried marsh (141 µg/L) and semidried marshes were (133 µg/L) were higher than in the completely dried marshes (93 µg/L), except for Majnoon marsh (162 µg/L) which was excluded from the mean. Seasonal and temporal differences were observed in SiO_2 concentration in Al-Hawizeh marshes during the study period. SiO_2 concentration in the never dried marsh and semi-dried marshes were low in summer (May to September) and high winter and early spring (October to February) unlike the completely dried marshes where the pattern was opposite.

Table 4–6: Concentration of the physical and chemical parameters and nutrients concentrations in Al-Hawizeh marshes during the study period.

	May 06	**Jun 06**	**Jul06**	**Aug 06**	**Sep 06**	**Oct 06**	**Nov 06**	**Dec 06**	**Jan 07**	**Feb 07**	**Mar 07**	**Apr 07**	**Feb 08**	**Aug 08**
Salinity (psu)														
Al-Udhaim	0.7	0.5	0.7	0.6	0.9	0.8	0.7	0.7	0.7	0.7	0.6	0.8	1.2	1.0
Al-Souda north	0.7	0.5	0.6	0.6	0.9	0.9	0.7	0.7	0.7	0.7	1.0	0.7	1.1	1.0
Um Al-Niaaj	0.6	0.5	0.6	0.5	0.6	0.6	0.8	0.5	0.4	0.5	0.7	0.9	1	1.0
Um Al-Warid	0.6	0.2	0.4	0.6	0.4	0.5	0.5	0.3	0.3	0.8	0.5	0.5	1.1	0.9
Al-Souda south	1.3	1.2	1.1	0.9	1.0	1.1	0.8	0.8	0.8	0.7	0.6	0.6	1.3	1.0
Baydha	1.1	1.1	1.1	0.9	0.9	0.9	0.9	0.8	0.9	0.7	0.6	0.6	1.3	1.1
Lissan Ijerda	1.2	1.3	1.7	1.6	1.8	1.6	1.6	1.4	1.2	1.1	1.1	1.0	1.6	1.2
Majnoon	1.2	1.1	1.3	1.1	1.3	1.3	1.3	1.3	1	0.9	0.9	0.9	1.1	0.7
pH														
Al-Udhaim	7.9	7.5	7.9	7.8	7.6	7.6	7.9	7.7	8.1	8.0	8.3	7.8	8.5	7.8
Al-Souda north	7.7	7.6	7.9	7.6	7.4	7.3	7.8	7.9	7.5	7.8	8.0	7.7	8.5	8.0
Um Al-Niaaj	8.1	8.1	8.1	8.4	7.9	7.9	7.9	8.1	8.3	8.2	8.6	8.0	8.4	8.1
Um Al-Warid	8.6	7.9	8.0	8.1	8.0	7.9	7.9	8.1	8.3	8.2	8.3	7.9	8.1	8.0
Al-Souda south	7.4	7.6	6.6	7.5	7.1	7.2	7.2	7.6	7.4	7.2	7.2	7.2	8.3	8.2
Baydha	7.5	8.0	7.7	7.7	7.8	7.8	7.9	7.8	7.6	7.7	8.1	7.6	8.0	8.1
Lissan Ijerda	8.4	7.5	7.7	8.0	7.8	7.7	8.2	8.2	8.4	8.3	8.5	8.1	8.2	8.1
Majnoon	8.2	7.3	6.7	8.4	8.4	8.2	8.4	8.4	8.4	8.3	8.5	8.4	8.8	8.4
DO (mg/L)														
Al-Udhaim	5.2	5.5	6.5	6.8	5.4	7.2	8.9	7.9	9.8	9.3	10.6	6.1	12.8	10.5
Al-Souda north	5	5.1	7	8.0	1.7	2.4	7.7	7.3	9.2	7.8	8.4	8.4	12.8	9.2
Um Al-Niaaj	9.1	8.3	10.6	6.1	7.9	10	9.9	8.9	11.8	8.8	10.6	7.9	11.5	8.1
Um Al-Warid	7.5	7.9	5.9	11.1	5.4	6.2	7.7	6.9	9.9	9.7	9.7	6.4	10.0	5.1
Al-Souda south	1.2	7.1	1.0	7.9	0.3	0.6	0.8	1.7	2.5	0.7	1.3	0.4	3.1	2.9
Baydha	5.5	6.8	4.8	9.0	5.4	8.6	8.5	6.7	7.7	6.9	8.6	6.8	10.0	6.8
Lissan Ijerda	8.6	6.8	4.1	9.0	4.1	6.7	9.5	8.6	10	7.8	8.5	8.9	9.0	8.2
Majnoon	4.9	0.9	5.8	11.5	4.8	7.2	8.7	8.7	9	7.5	7.5	7.2	8.6	7.9
WCD (m)														
Al-Udhaim	2.4	2.5	2.3	1.8	1.7	1.7	1.9	1.9	2.2	2.1	2	2.2		
Al-Souda north	2.6	2.9	2.6	2.6	2.2	2.2	2.5	2.4	3.1		2.9	2.9		
Um Al-Niaaj	2.7	2.7	2.5	2.4	2.1	2.1	2.2	2.2	2.4	2.5	2.4	2.5		
Um Al-Warid	2.7	2.5	2.4	2.3	2.1	2	2.1	2.1	2.5	2.4	2.4	2.5		

	May 06	Jun 06	Jul06	Aug 06	Sep 06	Oct 06	Nov 06	Dec 06	Jan 07	Feb 07	Mar 07	Apr 07	Feb 08	Aug 08
Al-Souda south	2.8	2.5	2.5	2.1	2.2	1.9	2.2	2.1	3.0	2.4	2.3	2.3		
Al-Baydha	2.6	3.1	2.3	1.3	1.6	2.7	2.1	2.3	3.1	2.1	2.2	3.4		
Lissan Ijerda	1.7	2.1	1.8	1.9	1	1.5	1.4	1.8	1.6	1.7	1.7	1.7		
Majnoon	1.9	2.5	1.5	1.4	1.2	1.0	1.1	1.2	1.5	1.6	1.5	1.4		
SRP(µg/L)														
Al-Udhaim	8.6	0.6	5.8	11.1	5.4	3.1	0.6	5.6	2.6	1.2	6.3	5.5	1.9	1.6
Al-Souda north	9.7	1.4	7.2	3.4	3.8	3.2	4.9	5.1	3.5	2.2	7.2	5.9	0.8	1.1
Um Al-Niaaj	10.4	0.1	6.6	5.6	2.1	1.8	4.3	5.0	2.7	1.3	6.6	15.4	1.8	1.4
Um Al-Warid	35.2	49.7	49.9	6.2	22.9	31.7	19.9	56.2	7.5	24.5	10.8	77.3	1.1	1.1
Al-Souda south	12.8	2.6	2.7	5.6	2.7	0.8	5.2	4.2	2.9	4.5	5.6	6.6	1.5	1.2
Al-Baydha	10	1.9	7	3.9	2.2	2.6	5.8	7	3.2	3.9	6.1	3.6	0.6	1.3
Lissan Ijerda	9.0	1.0	4.7	6.2	4.1	4.6	5.2	5.1	2.5	3.5	5.0	3.6	0.8	0.7
Majnoon	8.6	0.7	4.4	5.5	2.1	5.4	6.1	4.5	3.2	4.5	5.6	4.9	0.8	1.4
NO_3^- (µg/L)														
Al-Udhaim	24.1	37.2	48.4	8.8	6.8	<0.5	5.3	1.8	1.4	4.4	11.6	3.7	3.5	4.5
Al-Souda north	35.4	33.8	50.1	14.0	6.7	3.2	6.3	1.4	1.0	3.4	4.0	0.6	3.4	4.6
Um Al-Niaaj	32.3	47.4	44.3	14.2	6.0	<0.5	6.2	5.8	1.8	2.9	10.7	8.3	3.3	3.9
Um Al-Warid	51.3	40.6	48.4	115.9	61	29.4	29.5	1.4	2.6	12.5	26.9	21.6	3.4	3.6
Al-Souda south	46.8	53.1	31.1	10.8	3.0	3.7	4.9	2.5	3.9	1.4	2.7	1.6	3.0	4.1
Al-Baydha	43.1	51.8	38.1	21.0	12.2	5.2	6.6	2.4	1.3	3.6	5.0	1.7	3.3	4.5
Lissan Ijerda	42.1	45.2	51.1	9.4	3.7	4.0	4.6	2.4	0.1	3.0	4.9	1.3	3.5	4.5
Majnoon	47.9	36..0	51.6	7.4	2.6	2.6	5.0	0.9	<0.5	2.0	2.6	1.8	3.6	3.3
SiO_2 (µg/L)														
Al-Udhaim	148.5	135.2	99.4	252	283.5	198.9	175.4	114.6	95	138.8	94.2	143.3	67.7	32.0
Al-Souda north	139.4	63.2	166.4	244.7	451.6	381.6	197	141.6	85.4	155.3	79.7	100.7	67.9	49.3
Um Al-Niaaj	124.6	73.3	82.8	262.1	227.5	189.5	124.1	62.5	20.7	60.2	34.8	73.3	49.8	22.9
Um Al-Warid	135.9	99	80.5	130.7	116.5	119	97	65.2	25	43.4	18.5	114.5	25.7	31
Al-Souda south	87.4	64.1	86.0	188.7	316.3	361	160.3	114.1	72.6	25.6	7.7	11.1	39.1	28
Al-Baydha	91.1	43.3	95.3	205.3	283.7	434.1	282.2	228.1	147.5	64.4	3.8	23	45.7	40.8
Lissan Ijerda	42.9	17.2	12.8	38.3	65.3	194	90.6	15.8	1.7	0	3.8	6	49.2	32.7
Majnoon	124.9	50.9	93.8	166.5	231.8	438.6	293.7	196.8	191.9	232.2	96.7	83.1	41.4	29.2

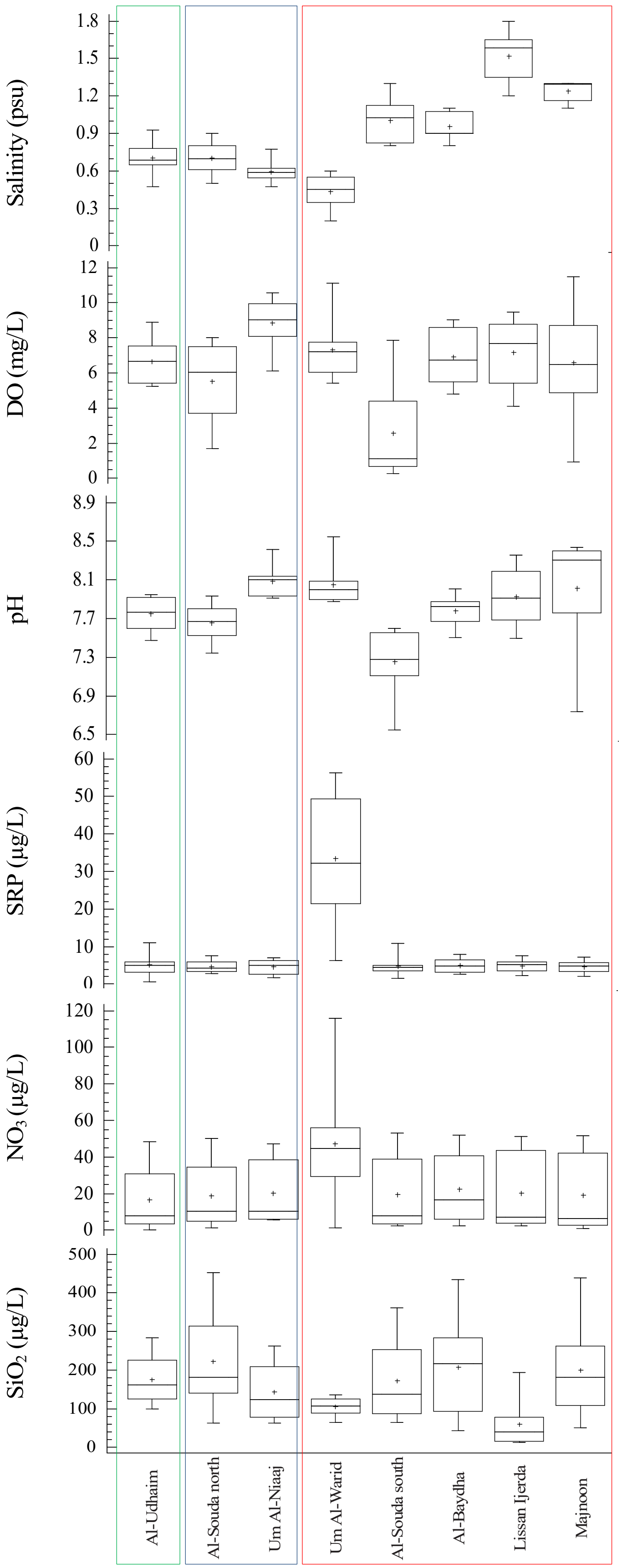


Figure 4–5: Box plots for the physical-chemical parameters and nutrient distribution in Al-Hawizeh marshes from April 2006 to April 2007, February 2008 and August 2008. The green box is the never dried marsh, the blue box includes semi – dried marshes, and the red box is for completely dried marshes.

4.4.4 Water Quality Parameters and Phytoplankton Distribution

RDA (Figure 4–6) was successful in relating the major axes of variation in average phytoplankton composition to environmental parameters; species-environment correlation for the axis 1 is 0.56, for axis 2 is 0.39. The sum of three canonical eigenvalues was 1.33. Salinity, pH, DO, SRP and NO_3^- were the main environmental parameters related to the phytoplankton distribution among the study areas (Figure 4–6, Table 4–7).

Most of the phytoplankton species were found in environments with high salinity and low nutrients. As nutrients are consumed by phytoplankton, the cause-effect relationship is likely reversed in this instance (i.e., the phytoplankton drive the environmental variables, rather than vice-versa).

Marshes that have direct water inputs showed different water characteristics and thus phytoplankton assemblages. Um Al-Niaaj marsh, on the contrary to Al-Souda north marsh, was positively related to DO and had low consideration of SiO_2, while Um Al-Warid marsh was extreme on axis 2, which was negatively related to salinity and positively related to nutrients and DO.

Completely dried marshes also Al-Udhaim, Al-Souda north, Al-Souda south and Al-Baydha marshes were gathered showed different water characteristic and thus phytoplankton assemblage. Majnoon marsh was positively related to salinity. Lissan Ijerda marsh was in low DO. Al-Souda south and Al-Baydha marshes were gathered close to Al-Udhaim marsh.

Harmful species *Snowella lacustris* (Chodat) Komárek & Hindák (snl) and *Oscillatoria curviceps* C.Agardh ex Gomont (osc) were associated with high salinity, especially in Majnoon marsh. *Amphora ovalis* (Kützing) Kützing (amo) was associated with high nutrients (NO_3^- and SRP), especially in Um Al-Warid marsh, indicating that they are eutrophic indicators, while *Nitzschia sigmoidea* (Nitzsch) W.Smith (nis) was associated with high nutrients, especially in Lissan Ijerda marsh.

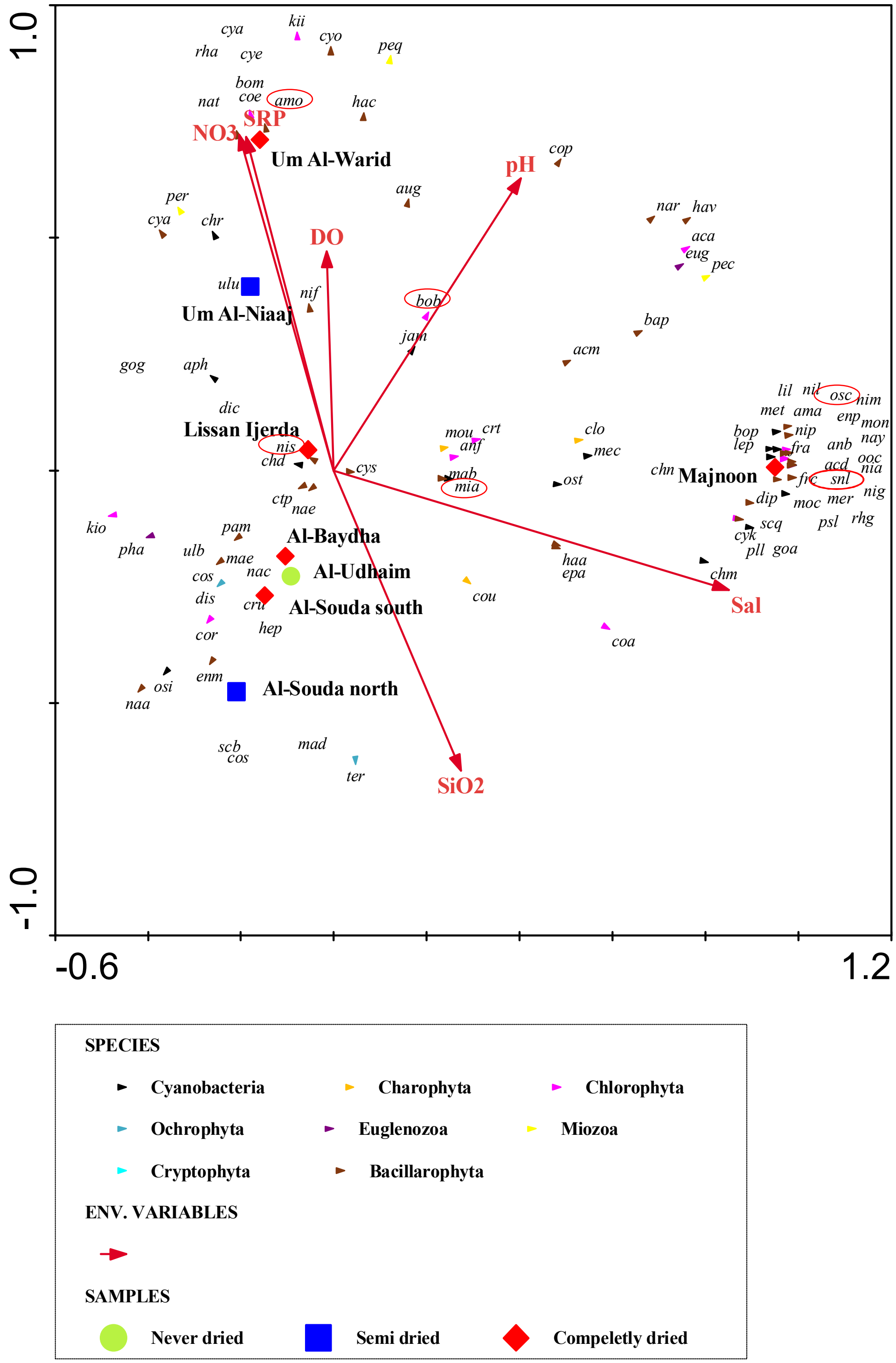


Figure 4–6: Redundancy analysis (RDA) for phytoplankton communities and environmental variables in the sampling stations of the Al-Hawizeh using the average data during the study period. Harmful species are in red loops.

Continued: Figure 4–6 - **Species Key**:

Aphanocapsa sp.	**aph**	*Achnanthes minutissima*	**ama**
Chroococcus dispersus	**chd**	*Amphora ovalis*	**amo**
Chroococcus minor	**chm**	*Bacillaria paxillifera*	**bap**
(Order) Chroococcales	**chr**	*Cocconeis placentula*	**cop**
Dolichospermum sp.	**anb**	*Cocconeis placentula var. euglypta*	**coe**
Gomphosphaeria aponina	**goa**	*Cymbella affinis*	**cya**
Jaaginema minimum	**jam**	*Cymbella aspera*	**cys**
Leptolyngbya perelegans	**lep**	*Denticula elegans*	**dip**
Limnococcus limneticus	**lil**	*Epithemia adnata*	**epa**
Merismopedia convoluta	**mec**	*Encyonopsis microcephala*	**enm**
Merismopedia elegans	**mer**	*Encyonema perpusillum*	**enp**
Merismopedia tenuissima	**met**	*Gomphonema gracile*	**gog**
Microcystis aeruginosa	**mia**	*Halamphora coffeiformis*	**hac**
Oscillatoria curviceps	**osc**	*Halamphora veneta*	**hav**
Oscillatoria sp.	**osi**	*Mastogloia braunii*	**mab**
Oscillatoria tenuis	**ost**	*Mastogloia elliptica*	**mae**
Planktolyngbya limnetica	**pll**	*Mastogloia danseyi*	**mad**
Pseudanabaena limnetica	**psl**	*Navicula cincta*	**nac**
Snowella lacustris	**snl**	*Navicula cryptonella*	**nar**
Closterium sp.	**clo**	*Navicula cryptocephala var. veneta*	**nay**
Cosmarium sp.	**cos**	*Navicula exilis*	**nae**
Cosmarium subcostatum	**cou**	*Navicula radiosa*	**naa**
Heimansia pusilla	**hep**	*Navicula tripunctata*	**nat**
Mougeotia sp.	**mou**	*Nitzschia acicularis*	**nia**
Acutodesmus acuminatus	**aca**	*Nitzschia frustulum*	**nif**
Acutodesmus dimorphus	**acd**	*Nitzschia gracilis*	**nig**
Ankistrodesmus falcatus	**anf**	*Nitzschia longissima*	**nil**
Coelastrum astroideum	**coa**	*Nitzschia microcephala*	**nim**
Coelastrum reticulatum	**cor**	*Nitzschia obtusa*	**nip**
Crucigenia sp.	**cru**	*Nitzschia sigmoidea*	**nis**
Kirchneriella irregularis	**kii**	*Rhoicosphenia abbreviata*	**rha**
Kirchneriella obesa	**kio**	*Rhopalodia gibba*	**rhg**
Monoraphidium contortum	**moc**	*Cyclotella atomus*	**cya**
Monoraphidium sp.	**mon**	*Cyclotella kuetzingiana*	**cyk**
Pandorina morum	**pam**	*Cyclotella meneghiniana*	**cye**
Pseudopediastrum boryanum	**scb**	*Cyclotella ocellata-kutzingiana*	**cyo**
Scenedesmus quadricauda	**scq**	*Ctenophora pulchella*	**ctp**
Botryococcus braunii	**bob**	*Fragilaria acus*	**fra**
Botryococcus protuberans	**bop**	*Fragilaria capucina var. vaucheriae*	**frc**
Botryococcus protuberans var. minor	**bom**	*Hantzschia amphioxys*	**haa**
Crucigenia tetrapedia	**crt**	*Ulnaria biceps*	**ulb**
Dictyosphaerium sp.	**dic**	*Ulnaria ulna*	**ulu**
Oocystis sp.	**ooc**		
Tetraëdriella regularis	**ter**		
Dinobryon sertularia	**dis**		
Euglena sp.	**eug**		
Phacus sp.	**pha**		
Peridiniopsis quadridens	**peq**		
Peridinium cinctum	**pec**		
Peridinium sp.	**per**		
Chroomonas nordstedtii	**chn**		
Aulacoseira granulata	**aug**		
Coscinodiscus sp.	**cos**		
Melosira varians	**acm**		

Table 4–7: Correlation matrix of the RDA for phytoplankton communities and environmental variables in the sampling stations of the Al-Hawizeh using the average data during the study period.

	SPEC AX1	**SPEC AX2**	**ENVI AX1**	**ENVI AX2**	**Salinity**	**pH**	**DO**	**SRP**	**NO_3^-**	**SiO_2**
SPEC AX1	1.0									
SPEC AX2	0.0	1.0								
ENVI AX1	1.0	0.0	1.0							
ENVI AX2	0.0	1.0	0.0	1.0						
Salinity	-1.0	-0.2	-1.0	-0.2	1.0					
pH	-0.4	-0.5	-0.4	-0.5	0.4	1.0				
DO	0.4	0.0	0.4	0.0	-0.4	0.5	1.0			
SRP	0.6	-0.4	0.6	-0.4	-0.6	-0.1	0.1	1.0		
NO_3^-	0.6	-0.4	0.6	-0.4	-0.6	-0.1	0.1	1.0	1.0	
SiO_2	-0.6	0.2	-0.6	0.2	0.5	0.0	-0.4	-0.4	-0.5	1.0

4.4.5 Changes in the Phytoplankton Community over Time

The PRC method was used to compare all other sites to the relatively undisturbed and never dried Udhaim marsh using the physical and chemical data (Figure 4–7). Deviation from the x-axis reflects a difference in physical-chemical parameters from the reference marsh. Majnoon, Um Al-Warid and Lissan Ijerda marshes were the most different from Udhaim marsh, while Al-Souda south, Al-Souda north, Al-Baydha, and Um Al-Niaaj were more similar. In this analysis, the variables TSS, salinity, SRP, DO and WCD had a strong influence. There was some indication of convergence of the sites towards the end of the analysis and in February 2008 none of the three marshes that diverged initially had high PRC scores.

The same approach was applied to the phytoplankton data (Figure 4–8). In this analysis, only Majnoon and Lissan Ijerda differed strongly from Al-Udhaim marsh, although the latter became similar after November 2006. *Nitzschia* sp. characterized the completely dried marshes with high salinity concentration, as judged by their high positive weighting on the PRC axis and environmental axes 1 of RDA (see Figure 4–6). As expected, the semi-dried marshes showed less deviation in water quality from the control site. By the end of the study, even Majnoon was more similar to the other sites.

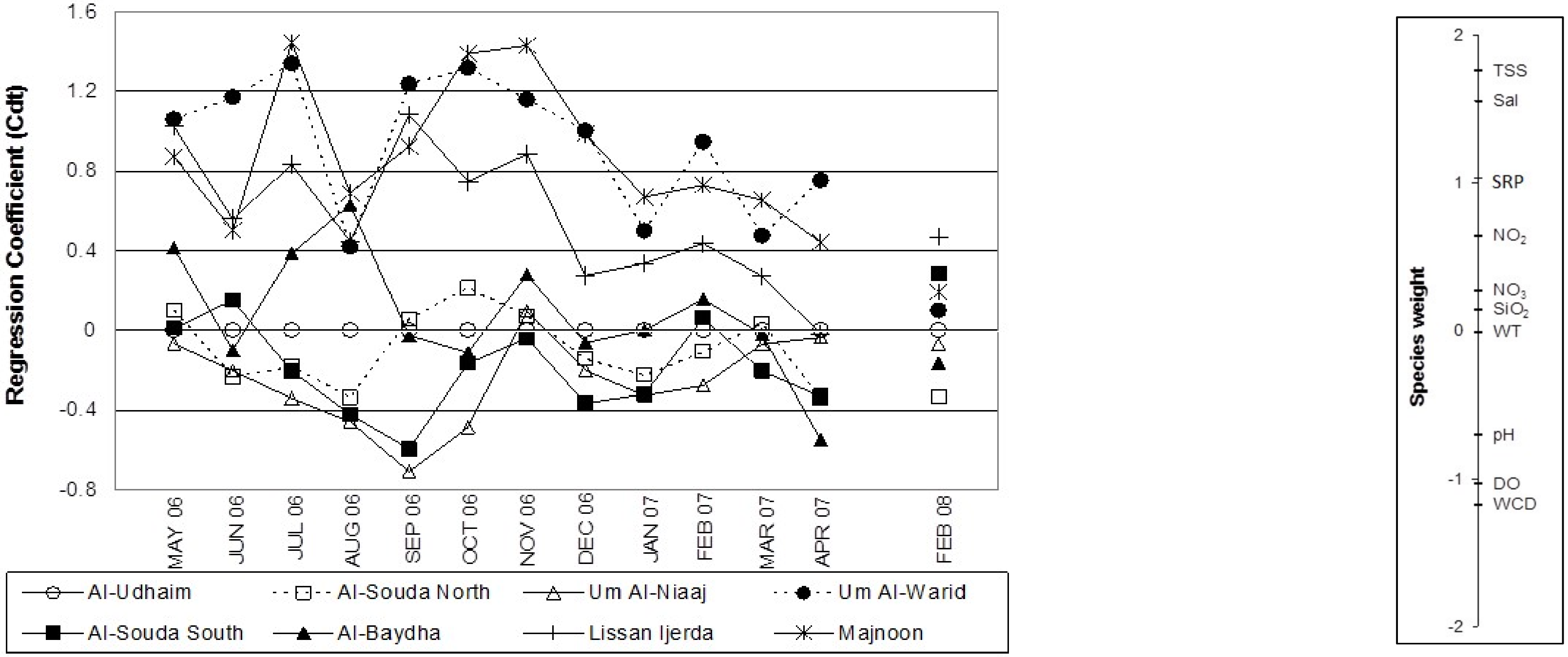
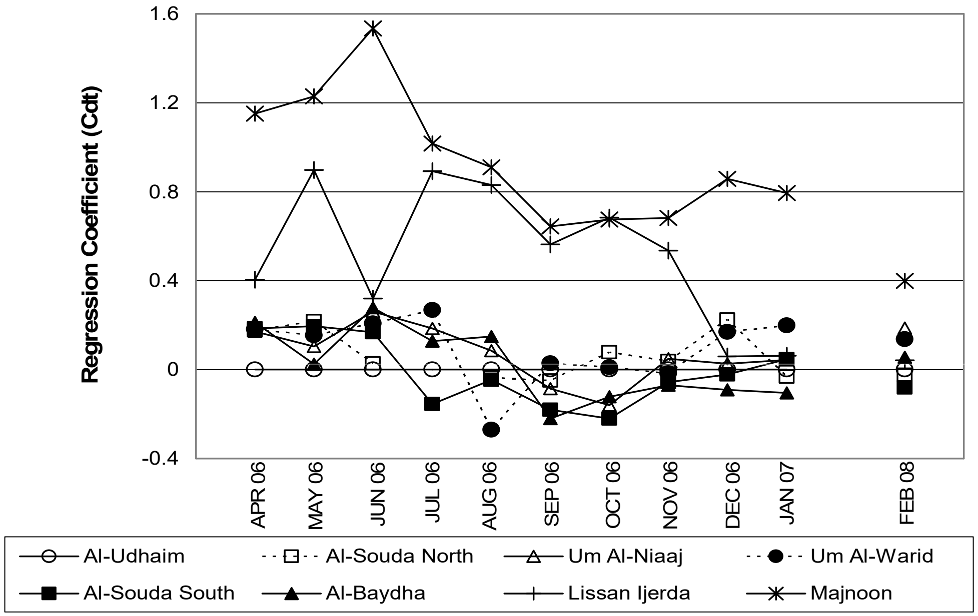


Figure 4–7: PRCs and species weights for water physical and chemical data (Al-Udhaim is the control site).



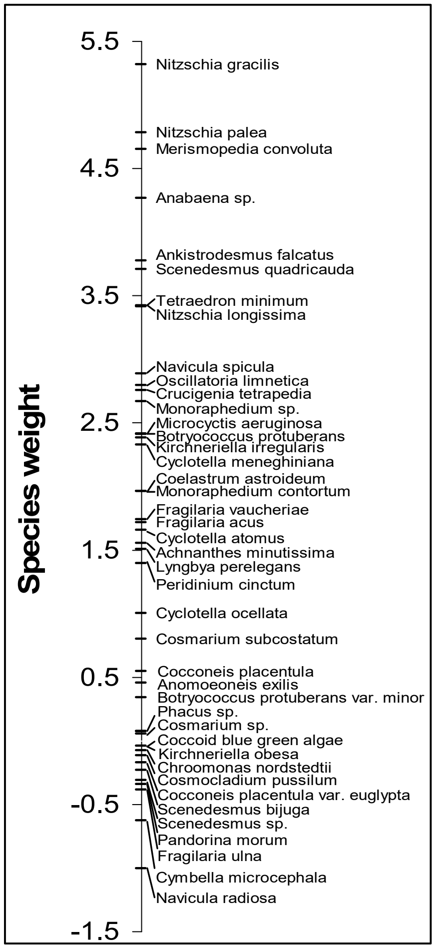


Figure 4–8: PRCs and species weights for phytoplankton data (using Al-Udhaim as the control site) excluding species with mean cell number < 5 cell/ml.

4.5 Discussion

The Biological assessment of Al-Hawizeh marshes provided a detailed picture of the phytoplankton assemblage over a full 11-month period. Since re-flooding in 2003, phytoplankton has been studied qualitatively and quantitatively in the Mesopotamian marshes; however, none of these studies adopted current references for identification and taxonomy. Although phytoplankton species in this study were identified based on older identification keys, the species identified were updated using a current taxonomy resource (Guiry and Guiry 2015). Using the updated taxonomy resource allowed me to identify two additional phyla and a total of fourteen classes.

The majority of the identified phytoplankton species during the study period were fresh water species, which is a good indication that the marshes are still floristically fresh marshes even with the general increase of their salinity over time (Chapters 2 &3) I did find that 9% and 3% of the species were euryhaline and brackish species, respectively. Harmful species with the potential to create health problems and negatively affect water quality were recorded in relatively low abundance comparing to the rest of the species. The Iraq Foundation (IF 2008) has reported a rare observation of the harmful dinoflagellate species *Peridinium cinctum* (O.F.Müller) Ehrenberg; however no report of large blooms or serious harm was recorded. In my study, *Peridinium cinctum* (O.F.Müller) Ehrenberg was recorded (up to 4892 cells/ml) all over the Al-Hawizeh marshes; however, no harmful impact has been noted. A few species of cyanobacteria (< 10 cell/ml), mostly the genus *Oscillatoria*, were reported in some historical studies (Maulood et al. 1981), and primarily in Al-Hammar marsh. This study indicates an increase of approximately 100 times in the harmful cyanobacteria group compared to the historical record. Such an increase in harmful species could lead to serious health issues, especially for humans who use marsh water for drinking (Hitzfeld et al. 2000, Antoniou et al. 2005, EPA 2012).

Differences in phytoplankton abundance were observed among the selected marshes within Al-Hawizeh (Table 4–4) suggesting that the once homogenous nature of Al-Hawizeh marsh (Hussain 1994) has been altered since inundation in 2003. However, differences were not evident in diversity or evenness, suggesting that the relative abundances of the species in each marsh are rather similar. The difference in phytoplankton abundance among the marshes is likely related to differences in water inputs and land uses.

Generally, the environmental parameters and phytoplankton communities of the marshes are related (Figure 4–6, Table 4–7) which reveal that flooding history of the marshes (never dried, semi-dried and completely dried) does not determine the present differences in phytoplankton but that they are related to water chemistry (Figure 4–6). The flow of water through the Al Hawizeh marsh complex has an important effect on each individual marsh (Mahamed 2008). The relation between phytoplankton assemblage and environmental parameters revealed several findings. The reduction of class Bacillariophyceae, which was abundant during the pre-desiccation period (see Table 1–2 in Chapter 1; Hussain, 1994,Yaqoub, 1994) relative to class Chlorophyceae after re-flooding (Talib 2009; current study) may be related to the reduction in SiO_2 concentrations, especially in the marshes that are located far from the major water inputs as SiO_2 is required by diatoms (Gibson et al. 2000). The origin of SiO_2 in the marshes is likely from weathering processes upstream. This study shows that the current concentrations of SiO_2 among the Al-Hawizeh marshes are 10 times lower than the previous records before desiccation (Maulood 1979; Arajee 1988; Hassan 1988). This is mostly related to the decrease in rivers discharge (see Figure 2–5), changes in the annual pattern of water discharge (Figure 2–6), trapping in the upstream reservoirs, and changing in water parameters (high pH and low DO), which can affect the silicate mineral dissolution and thus decrease SiO_2 concentration in the water (White and Brantley 1995, Maavara et al. 2014, Maavara et al. 2015, Van Cappellen and Maavara 2015). An inverse relation between SiO_2 and NO_3^- has been observed (Table 4–7), which could be a result of the changing in the biogeochemical cycle silica with increasing nitrogen (Conley et al. 1993).

Conley et al. (1993) indicate that increasing nutrient may leads to increases total N and total P concentrations (and not Si) in the water that can lead to fleeting nutrient limitation of diatom biomass due to lack of dissolved silicate. Thus, high diatoms production can lead to an increased accumulation of biogenic silica in sediments, eventually reducing the dissolved silicate concentration in the water.

The presence of cyanobacterial species, e.g. *Dolichospermum* sp., even if it contributed only 10% of the total phytoplankton abundance in Al-Hawizeh marshes, can be a sign for the potential for eutrophication (Smith et al. 1999) that can indicate or lead to serious water quality problems. This study also indicates that the WQPs most related to the phytoplankton community were nutrients (SRP and NO_3^-; Table 4–7), especially in the marshes that were close to river inputs. Al-Warid and Al-Souda north marshes have external inputs, such as agricultural discharge with elevated P and N. Although, Um Al-Niaaj also has external agriculture inputs, NO_3^- and SRP concentrations were low. This is likely because the volume of Um Al-Niaaj marsh is about 4 times larger than Um Al-Warid and Al-Souda north marshes. Nutrients can also be consumed, or in the case of NO_3^-, denitrified (Alsterberg et al. 2012). Low DO in Al-Souda south marsh can be an indication of nutrient enrichment (Eichel et al. 2014, Xu et al. 2014).

Lower levels of nutrients and lower biomass characterize the never dried Al-Udhaim marsh which has high submerged vegetative cover that causes low light penetration for phytoplankton photosynthesis. The biomass, richness, chl *a* and nutrient parameters in Al-Udhaim were all low. Decomposition of abundant vegetation is potentially controlling the increase of nutrients and to a certain extent, chl *a* in never-dried marsh sub-ecosystems (Al-Sahaf 1975, Al-Musawi and Husain 1994, Donnelly et al. 1997, Douabul et al. 2012).

Water to the completely dried marshes (Al-Baydha, Um Al-Warid, Lissan Ijerda and Majnoon) flows through the other marshes bringing higher salts. The salinity increases can also be attributed to the re-dissolving of accumulated salts in dried sediments after re-flooding (see

Chapter 2; Blinn 1993; Blinn et al. 2004). The higher nutrients in the completely dried marshes appear to be favourable to phytoplankton and increased abundance and richness are a result, especially within Majnoon and Lissan Ijerda.

The PRC results illustrate that both the water quality and phytoplankton communities are recovering, i.e., approaching the state of the Al-Udhaim marsh. The Majnoon and Lissan Ijerda marshes that were severely damaged during the desiccation period, with embankments and war impacts, show less convergence with Al-Udhaim. These marshes were different in both their water quality characteristics (Figure 4–7) and biological assemblage (Figure 4–8) from the never dried marsh during the study period, while marshes closer to the river inputs showed stronger evidence of recovery. It might be expected that reclamation of a wetland surrounded by desert, because of the isolation of the marshes from other freshwater wetlands, may be slowed by the distance to sources of colonizers. Fortunately, despite the potentially catastrophic anthropogenic impacts (Section 1.1.2), the phytoplankton trends illustrated by the PRC analysis show promise that these marshes, especially those located in the north part of the Al-Hawizeh, may be recovering

Conclusions & Recommendations

- **Ecological Changes**

The hydrological changes and the insufficient water supply are challenges to the recovery process. However, marshes those are close to water inputs show good evidence of recovery. Salinization and water shortage are the main factors deteriorating and damaging the ecological situation of the marshes. Therefore, these two factors should be investigated intensively to design a better recovery plan and suitable recovery methods for the Mesopotamian marshes. The hydrological history of the Mesopotamian marshes is complex. Water shortages first took their toll following extensive dam construction in Turkey during the mid-1970s. The huge water reduction reduced the discharge of the Tigris and the Euphrates Rivers into the marshes by an alarming 84%. Desiccation of the region quickly ensued and salinity issues rapidly deteriorated ecosystem quality. The increase in salinity of the Tigris and Euphrates Rivers in the early 1980s aggravated the impact of desiccation on salinization in the Mesopotamian marshes and caused serious ecological problems. Thus, continued water shortages and salinization became obstacles to the recovery process of the Mesopotamian. My analysis (Chapter 2) illustrates that the significant increase in salinity of the Mesopotamian marshes is mostly related to the increase in the average salinity level of the water inputs, the longer residence time of the water in the marshes, and possibly the dissolution of accumulated salts on surface sediments in the system. According to the Water Management Plan of the Mesopotamian Marshes issued by MoWR, water is non-existent in the region and there is no indication of an alternative water supply except using the MOD that needs extensive and expensive treatment.

Differences in water quality between pre-desiccation and after the re-flooding generally reflect the impact of desiccation and water shortage within the Mesopotamian marshes. Salinity and nitrate increased after desiccation with the exception of salinity levels in Al-Hawizeh marsh. These actually decreased, likely indicating more efficient flushing than before. My study used a limited number of WQPs to assess the water quality of the Mesopotamian marshes, so I must be cautious in discussing the changes in water quality over time and whether these changes are highly significant or not. For future studies, it is highly recommended to investigate a wider range of WQP including organic and inorganic components, toxic materials and chemicals that could have been deposited during the war period.

Using Al-Udhaim marsh as an indicator of the historical condition was based on its hydrological status. How close the ecological characteristics of Al-Udhaim are to the historical condition of the marshes before desiccation was not measured. Nonetheless, the advantage of never having been dried could give an indication of what the ecological structure of the marshes might have been if they were never dried, taking under consideration the natural impacts like global warming and the stressor of water shortage.

The research presented herein has documented for the first time that diatoms are not the only dominant group of phytoplankton, at least in the Al-Hawizeh marshes. The study also observes 1) several euryhaline and brackish species that are widely distributed over Al-Hawizeh marsh, 2) an increase of harmful phytoplankton species relative to the historical record, especially in high salinity marshes, and 3) large abundance of cyanobacteria, that might be attributable to the increase in nitrogen level, especially for the southern marshes of Al-Hawizeh. This change in the phytoplankton assemblage may have significant implications with regards to the biodiversity and ecological recovery of Al-Hawizeh marshes in the future. Based on the biological assessment of Al-Hawizeh marsh, anthropogenic activities that contributed to the deterioration of water quality in the Central and Hammar marshes have not had a substantial impact on the water quality in the northern part of Al-Hawizeh. Perhaps the inherent recovery capacity of the marshes has buffered the impact but, in any case, the results of this study show promise that recovery of these marshes may be successful. For future studies it is important to do biological assessment for the Al-Hammar and Central marshes in order to have a complete picture of how the phytoplankton is changing in these areas, and to expand the taxa involved to cover other essential ecological functional groups such as zooplankton and macrophytes.

Signs of Recovery

The study indicates that increasing of the salinity of the Tigris and the Euphrates are one of the sources to increase salinity of the Mesopotamian marshes. Nevertheless, Al-Hawizeh receives fresher water than other marshes. The difference in salt mass in the Al-Hawizeh at the beginning and end of the study indicates a decrease, which is congruent with its decline in water level and decrease in salinity. The estimated amount of salt entering and leaving Al-Hawizeh during the study period shows a net loss of salt. The estimated salinity in Al-Hawizeh coincides with the observed, indicating that accumulated salt has been cleared from the system.

Comparing both the water quality and phytoplankton communities between re-flooded marshes and never dried marsh in Al-Hawizeh illustrate sing of recovering, i.e., approaching the state of the Al-Udhaim marsh, especially in northern marshes. This can be a good indication for resuscitation.

Managing the Recovery Process

It is important from the management point of view, given the critical hydrological constraints in Iraq, to concentrate conservation efforts on the marshes that have the most sustainable ecological foundation. In this study, I found that marshes that are close to water inputs, particularly Um Al-Niaaj marsh in Al-Hawizeh, show good evidence of recovery. Thus prioritizing this area with a local management plan is more likely to lead to good results.

Water quality assessment indicates that salinity is affecting the ecological structure (chemical & biological) of the marshes, especially in the south of Al-Hawizeh. This could be a challenge for managing the recovery of these marshes because of the water shortage. Increasing nutrients, mostly due to agriculture discharge, should be treated to control the amount of nutrients entering the system and reduce the impact of nitrification. From the management point of view, monitoring phytoplankton assemblage can help to identify stressors like salinity and increasing nutrients. Regular phytoplankton monitoring will allow resource managers to evaluate the condition of the marshes and may provide some indication of the type of stressor damaging them.

In order to manage the marshes (preferably using local management plans), Iraq also needs to collect comprehensive data on water discharge and quality, find suitable and sustainable alternative water supplies, and proscribe laws that protect the marshes from encroachments. As suggested in the current management plan of the MoWR, the ministry is providing a sufficient water discharge for the west part of the Al-Hammar marshes from the MOD. However, as it has been mentioned earlier, the MOD water is an untreated agriculture drainage canal that contains high salinity, toxic materials and nutrients. I suggested that MoWR should treat the discharge water from the MOD to the marshes after reducing its salinity and nutrient levels. The current management plan of the Mesopotamian marshes should be revised, taking under consideration; 1) the shortage of water and low flow and the loss of external water inputs from Iran to Al-Hawizeh marsh, 2) the reduction of Shatt Al-Arab water level, 3) natural threats like global warming, and 4) the amount of water required for oil production and development.

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Appendices

APPENDIX 1

Table A1: Summary of the study surveys.

Surveys	Sponsor	Organization that carried the work	Marsh	Site description	Period	Parameters used in this study
WB	**IMET**	Iraq Foundation (NGO)	HZ, CM, HM	Main Water Inputs and Outlets	May 2006-February 2007 (monthly)	WD, WQP
MRA	**USAID**	Iraq Foundation (NGO)	CM, HM	Two Re-flooded Marshes	March 2004-March 2005 (monthly)	WQP, MI, TSS, DN
KBA	**CIDA**	Iraq Foundation (NGO)	HZ, CM, HM	Thirty two Re-flooded marshes	March 2005, June 2005, January 2006, and July 2006	WQP
GS	**UNEP**	Nature Iraq (NGO)	CM, HM	Three marshes in each marshland	May 2005, August 2005, September 2005, and December 2005	Water Salinity
NB	**CIDA**	Nature Iraq (NGO)	HZ	Eight marshes	April 2006-April 2007 (monthly)	WQP, MI, TSS, DN, phytoplankton, Chl a
CIMI-I	**CIDA**	Nature Iraq (NGO), Marine Science Center in University of Basra	HZ, CM, HM	Twelve marshes	October 2006-March 2007 (monthly)	WQP, MI, TSS, DN, Chl a
CIMI-II	**CIDA**	Nature Iraq (NGO), Marine Science Center in University of Basra	HZ, CM, HM	Twelve marshes	February 2008 and August 2008	WQP, MI, TSS, DN, Chl a

Projects: WB= Water Budget; MRA= Mesopotamian Marshes Restoration Assessment, KBA= Key Biodiversity Areas; GS= General Survey; NB= Nutrients Budgets, CIMI= Canada-Iraq Marshlands Initiative (I & II)

Monitoring parameters: WD= Water Discharge; WQP= water quality parameters including water temperature (WT), salinity, dissolved oxygen (DO), and pH; TSS= total suspended solids; DN= Dissolved Nutrients include Soluble Reactive Phosphate (SRP), nitrate (NO_3), nitrite (NO_2), and silicate (SiO_2); MJ= Major Ions include calcium (Ca), magnesium (Mg), chloride (Cl), and sulfate (SO_4); Chlorophyll a (Ch a)

Table A2: GPS coordinates and site description of the sampling stations.

Sampling stations	Latitude (N)			Longitude (E)			Site description	Project
Al-Hawizeh marshes								
Al-Msharah (1)	31	42	16	47	36	6	Water input	WB
Al-Zubair (2)	31	38	56	47	34	38	Water input	WB
Um Al-Toos (3)	31	37	0	47	33	8	Water input	WB
Al-Husachi (4)	31	34	4	47	30	3	Water input	WB
Al-Kassara (5)	31	21	39	47	26	57	Water outlet	WB
Al-Sweeb (6)	30	58	6	47	29	28	Water outlet	WB
Al-Udhaim (21)	31	41	30	47	44	0	Continually wet marsh	KBA, CIMI-I, CIMI-II, NB
Um Al-Niaaj (22)	31	36	0	47	36	0	Semi-dried marshes	KBA, CIMI-I, CIMI-II, NB
Al-Souda North (23)	31	40	23	47	40	0	Semi-dried marshes	CIMI-I, CIMI-II, NB
Um Al-Warid (24)	31	34	47	47	31	7	Completely-dried marshes	CIMI-I, CIMI-II, NB
Al-Souda South (25)	31	25	15	47	36	56	Completely-dried marshes	CIMI-I, CIMI-II, NB
Al-Baydha (26)	31	22	1	47	38	46	Completely-dried marshes	CIMI-I, CIMI-II, NB
Majnoon (28)	31	7	59	47	35	33	Completely-dried marshes	CIMI-I, CIMI-II, NB
Lissan Ijerda (27)	31	17	27	47	34	37	Completely-dried marshes	KBA, CIMI-I, CIMI-II, NB
Central marshes								
Al-Gharaf (7)	31	9	52	46	36	40	Water input	WB
Abu Sobatt (8)	30	58	6	47	2	20	Input and outlet	WB
Abu Al-Narssi (9)	30	58	4	47	3	40	Input and outlet	WB
Abu Cholan (10)	30	58	16	47	1	20	Input and outlet	WB
Al-Subagaia (11)	30	58	6	47	9	3	Input and outlet	WB
Al-Khainziry (12)	30	58	4	47	8	24	Input and outlet	WB
Abu Jathiaa (13)	30	58	2	47	9	27	Input and outlet	WB
Sabaa (14)	30	58	1	47	8	1	Input and outlet	WB
Al-Baderia (15)	30	58	8	47	10	15	Input and outlet	WB
AlKhiala (16)	30	58	9	47	10	42	Input and outlet	WB
Al-Sewelmat (28)	31	28	27	47	3	41	Monitoring station	GS
Al-Baghdadia (29)	31	1	20	47	2	14	Monitoring station	KBA, CIMI-I, CIMI-II, NB
Abu Zarag (30)	31	8	57	46	37	16	Monitoring station	MRA, KBA, CIMI-II
Badir Al-Ramaidh (31)	31	5	30	46	39	51	Monitoring station	GS
Al-Bsaida (32)	30	59	35	47	13	14	Monitoring station	KBA
Zichri (33)	31	3	19	47	13	19	Monitoring station	KBA
Al-Muajid (34)	31	5	0	46	38	3	Monitoring station	KBA, CIMI-I, CIMI-II, NB
Al-Fuhod (35)	30	59	10	46	43	32	Monitoring station	KBA
Al-Hammar marshes								
Al-Mansoury (17)	30	40	28	47	37	41	Input and outlet	WB
Al-Meshib (18)	30	40	49	47	37	39	Input and outlet	WB
Al-Dawadi (19)	30	39	33	47	39	35	Input and outlet	WB
Al-Shafia (20)	30	51	17	47	32	10	Input and outlet	WB
Al-Auda (36)	31	38	29	46	51	5	Monitoring station	KBA, CIMI-I, CIMI-II, NB
Al-Nagara (37)	30	40	4	47	38	38	Monitoring station	KBA, CIMI-I, CIMI-II

Sampling stations	Latitude (N)			Longitude (E)			Site description	Project
Al-Burka (38)	30	52	41	46	56	2	Monitoring station	KBA, CIMI-I, CIMI-II
Al-Tina (39)	30	53	59	46	51	59	Monitoring station	KBA
Al-Bhayra (40)	30	46	54	47	3	1	Monitoring station	KBA
Um Nakhla (41)	30	49	16	46	38	32	Monitoring station	KBA
Al-Khwasa (42)	30	46	41	46	39	27	Monitoring station	KBA
Shweria (43)	30	46	57	46	37	28	Monitoring station	KBA
Al-Jeweber (44)	30	56	45	46	36	55	Monitoring station	GS
Al-Kurmashia (45)	30	47	56	46	37	25	Monitoring station	MRA, KBA, GS

APPENDIX 2

Table B 1: Descriptive statistics of water quality parameters observed in the Mesopotamian marshes historically from 1978 to 1985 and after inundation from 2004 to 2008.

	WCD	LP	pH	DO	TSS	Salinity	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	NO_3^-	SRP	TDS	BOD
Central Marshes (Al-Baghdadia 1978-1979)														
No. of observations	5.0	5.0	5.0	3.0		5.0			1.0	1.0	5.0	5.0	5.0	
Minimum	2.0	0.2	7.1	4.5		0.2			39.0	24.0	3.0	1.0	0.3	
Maximum	3.5	3.5	8.2	5.3		0.7			39.0	24.0	81.0	26.0	1.9	
Mean	2.6	1.7	7.7	4.9		0.4			39.0	24.0	38.2	13.4	1.0	
Standard deviation (n)	0.6	1.2	0.4	0.3		0.2			0.0	0.0	25.7	8.0	0.7	
(Al-Baghdadia 1983-1984)														
No. of observations			9.0	9.0		9.0	9.0	9.0			8.0	8.0		
Minimum			7.4	3.1		0.6	11.0	32.0			0.4	0.1		
Maximum			8.0	8.5		2.2	97.0	88.0			1.2	1.4		
Mean			7.8	5.7		1.0	37.7	56.8			0.9	0.6		
Standard deviation (n)			0.2	1.6		0.4	31.2	21.8			0.3	0.4		
(Al-Baghdadia 2005 – 2007)														
No. of observations	29.0	2.0	112.0	122.0	124.0	112.0	49.0	49.0	49.0	48.0	70.0	93.0	32.0	35.0
Minimum	0.2	0.8	6.5	1.0	1.0	0.7	2.4	1.1	2.0	12.5	0.4	0.1	0.8	0.2
Maximum	2.5	1.2	8.9	15.1	78.4	5.6	521.0	388.0	1278.0	1595.3	372.2	78.3	3.4	22.8
Mean	1.3	1.0	8.0	5.8	7.6	1.5	100.0	96.6	494.0	432.6	22.6	8.3	2.2	4.4
Standard deviation (n)	0.5	0.2	0.6	3.0	9.4	0.7	91.6	77.5	310.7	357.4	53.4	11.5	0.7	6.0
(Abu Zarag 2004-2006)														
No. of observations	74.0	72.0	85.0	84.0	71.0	83.0					76.0	92.0		
Minimum	0.2	0.2	7.2	0.3	0.4	0.2					0.2	0.1		
Maximum	5.0	3.0	9.5	18.4	64.0	7.6					26.7	122.4		
Mean	1.9	0.9	8.1	6.2	13.1	1.0					2.5	15.9		
Standard deviation (n)	0.9	0.6	0.4	4.0	12.6	1.1					4.3	22.0		
Al-Hammar Marshes (Al-Burka 1985)														
No. of observations	14.0	36.0	35.0	36.0		36.0	36.0	36.0			36.0	36.0		
Minimum	0.3	0.3	7.6	1.0		1.3	16.0	11.0			0.3	0.1		
Maximum	8.0	1.2	8.6	12.0		4.3	311.0	251.0			9.2	0.9		
Mean	1.2	0.7	8.1	6.9		2.5	157.4	109.4			1.7	0.4		
Standard deviation (n)	1.9	0.2	0.3	2.6		0.7	85.1	64.0			1.7	0.2		
(Al-Burka 2005-2008)														
No. of observations	6.0		53.0	58.0	65.0	56.0	27.0	28.0	28.0	28.0	25.0	46.0	22.0	25.0
Minimum	1.2		7.2	1.0	0.8	1.2	12.2	8.2	12.0	46.9	0.9	1.5	0.6	0.4
Maximum	1.8		8.8	11.9	73.7	3.3	276.6	238.1	1538.8	1737.5	196.0	44.2	3.0	14.6
Mean	1.6		8.1	6.2	12.5	2.0	92.4	94.6	523.0	516.9	18.9	6.0	2.2	4.4
Standard deviation (n)	0.3		0.5	3.4	13.0	0.6	73.2	64.0	319.5	408.3	38.6	7.3	0.5	3.4
(Al-Kirmashia 2004-2008)														
No. of observations	32.0	29.0	45.0	45.0	37.0	40.0	2.0	2.0	5.0	5.0	36.0	43.0	1.0	2.0
Minimum	0.2	0.2	7.2	0.3	1.8	1.0	139.0	33.5	362.0	8.4	0.3	0.1	2.2	1.0
Maximum	5.0	3.0	8.9	8.6	69.2	5.7	228.5	151.6	1131.5	1524.4	4.8	62.3	2.2	1.8
Mean	1.6	0.7	7.9	4.7	23.9	1.8	183.7	92.6	623.9	333.9	1.2	14.4	2.2	1.4
Standard deviation (n)	1.1	0.7	0.4	2.1	18.5	1.0	44.7	59.1	282.6	595.8	1.2	11.5	0.0	0.4
(Al-Naggara 2006-2007)														
No. of observations	23.0		45.0	47.0	48.0	46.0	20.0	20.0	20.0	20.0	34.0	36.0		10.0
Minimum	0.7		6.9	1.4	1.0	1.1	12.2	7.5	5.0	62.7	0.4	0.1		0.8
Maximum	4.0		8.9	12.4	46.8	3.2	184.4	196.2	967.6	1169.9	367.9	25.1		8.0
Mean	1.9		7.9	7.3	16.3	2.0	80.9	84.5	443.9	564.3	29.2	5.8		4.1
Standard deviation (n)	0.8		0.5	2.2	12.0	0.6	62.7	51.5	321.8	341.1	82.9	6.5		2.3
Al-Hawizeh Marshes (Majnoon 1983-1984)														
No. of observations			9.0	9.0		5.0	9.0	9.0			8.0	8.0		
Minimum			8.0	1.1		3.4	28.0	23.0			0.4	0.2		
Maximum			9.2	8.9		6.5	249.0	3265.0			3.4	1.9		
Mean			8.5	5.7		5.5	134.8	602.2			1.6	0.7		
Standard deviation (n)			0.3	2.8		1.3	67.3	956.6			1.1	0.5		
(Majnoon 2006-2008)														
No. of observations	16.0	14.0	21.0	21.0	11.0	19.0	2.0	2.0	2.0	2.0	11.0	11.0	7.0	7.0
Minimum	1.0	0.3	6.7	1.3	5.0	0.9	8.3	14.9	42.1	367.8	0.4	2.1	1.0	0.8
Maximum	2.5	0.8	8.8	11.7	43.4	1.3	124.2	81.6	551.8	372.2	51.6	7.2	3.8	4.7
Mean	1.5	0.5	8.3	7.6	23.0	1.1	66.3	48.3	296.9	370.0	14.5	4.7	2.3	2.2
Standard deviation (n)	0.3	0.2	0.4	2.0	10.9	0.2	58.0	33.3	254.8	2.2	19.2	1.4	1.0	1.2
(Al-Udhaim 2006-2008)														
No. of observations	68.0	59.0	90.0	90.0	42.0	88.0	2.0	2.0	2.0	2.0	12.0	11.0	74.0	2.0
Minimum	1.6	1.6	6.8	1.2	0.7	0.4	46.3	35.7	222.4	265.9	0.5	0.6	0.8	3.0
Maximum	2.7	2.5	8.8	12.8	6.0	1.0	128.3	87.5	469.3	273.9	48.4	12.0	2.0	3.5

	WCD	LP	pH	DO	TSS	Salinity	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	NO_3^-	SRP	TDS	BOD
Mean	2.1	2.0	7.9	6.9	2.3	0.7	87.3	61.6	345.8	269.9	12.8	4.9	1.7	3.3
Standard deviation (n)	0.2	0.2	0.4	3.3	1.2	0.1	41.0	25.9	123.5	4.0	14.9	2.8	0.3	0.3
(Um Al-Niaaj 2006-2008)														
No. of observations	79.0	63.0	146.0	150.0	102.0	146.0	32.0	33.0	33.0	33.0	56.0	66.0	74.0	47.0
Minimum	1.8	1.3	6.9	1.0	0.5	0.3	1.3	4.4	17.9	16.4	1.5	0.1	0.7	0.6
Maximum	3.0	2.7	9.5	14.4	34.0	1.3	136.3	165.2	952.0	673.6	364.0	179.2	2.4	8.0
Mean	2.4	2.3	8.1	7.3	4.6	0.6	56.8	55.8	333.7	273.8	88.5	26.6	1.5	2.7
Standard deviation (n)	0.2	0.2	0.4	3.3	5.8	0.2	39.8	42.6	215.0	156.9	93.0	28.9	0.4	2.1
(Lissan Ijerda 2006-2008)														
No. of observations	23.0	14.0	30.0	30.0	18.0	28.0	2.0	2.0	2.0	2.0	18.0	18.0	9.0	6.0
Minimum	0.2	0.5	7.5	1.0	1.4	0.8	17.3	11.5	66.4	281.7	0.1	0.1	1.4	0.5
Maximum	2.1	1.8	8.5	12.5	97.8	7.8	131.2	121.5	412.8	779.9	51.9	65.4	2.8	6.5
Mean	1.2	1.5	8.2	7.3	14.8	1.5	74.3	66.5	239.6	530.8	10.2	8.1	2.1	2.8
Standard deviation (n)	0.7	0.3	0.3	2.6	24.4	1.2	56.9	55.0	173.2	249.1	16.6	14.1	0.4	2.1
(Um Al-Warid 2006-2008)														
No. of observations	22.0	15.0	73.0	77.0	71.0	74.0	32.0	32.0	32.0	32.0	52.0	62.0	37.0	32.0
Minimum	1.5	0.5	6.8	1.0	1.0	0.2	2.4	1.7	12.2	7.9	1.3	1.8	0.6	0.8
Maximum	2.7	2.5	9.0	13.5	78.6	0.8	132.3	155.5	1142.0	691.3	552.2	87.6	2.0	12.4
Mean	2.3	1.5	8.1	7.3	20.0	0.5	51.1	55.7	259.4	256.1	125.8	36.1	1.3	4.2
Standard deviation (n)	0.3	0.8	0.4	3.3	21.0	0.2	39.4	27.0	203.1	163.6	136.3	23.2	0.4	3.0
(Al-Souda north 2006-2008)														
No. of observations	15.0	13.0	24.0	24.0	12.0	22.0	2.0	2.0	2.0	2.0	12.0	12.0	16.0	6.0
Minimum	2.2	2.0	7.2	1.5	1.1	0.5	74.8	48.1	216.1	31.3	0.6	0.2	0.8	0.8
Maximum	3.1	3.1	8.5	12.8	3.2	1.0	128.3	65.6	484.8	32.9	35.4	7.6	2.6	4.0
Mean	2.7	2.6	7.8	7.6	2.1	0.7	101.5	56.9	350.4	32.1	9.6	4.5	1.7	2.1
Standard deviation (n)	0.3	0.4	0.3	2.3	0.6	0.1	26.8	8.8	134.3	0.8	11.7	1.9	0.5	1.1
(Al-Baydha 2006-2008)														
No. of observations	17.0	15.0	24.0	24.0	12.0	22.0	2.0	2.0	2.0	2.0	12.0	12.0	13.0	6.0
Minimum	1.3	1.3	7.5	1.0	0.9	0.6	14.2	7.5	73.5	222.5	1.3	2.6	1.2	1.2
Maximum	3.4	3.4	8.9	9.1	3.9	1.1	61.1	48.7	485.4	248.2	51.9	8.0	2.8	4.8
Mean	2.5	2.3	7.9	6.9	2.1	0.8	37.7	28.1	279.4	235.3	16.1	4.6	1.7	2.8
Standard deviation (n)	0.6	0.5	0.4	1.6	0.9	0.2	23.5	20.6	205.9	12.8	17.5	1.7	0.4	1.1
(Al-Souda south 2006-2008)														
No. of observations	17.0	15.0	24.0	24.0	12.0	22.0	2.0	2.0	2.0	2.0	12.0	12.0	16.0	6.0
Minimum	1.9	1.9	6.5	0.2	1.4	0.6	79.9	56.3	313.7	271.9	1.4	1.5	1.4	1.1
Maximum	3.0	3.0	8.3	8.0	3.9	1.3	144.3	63.2	481.6	283.8	54.0	6.6	2.0	24.0
Mean	2.4	2.3	7.4	1.9	2.2	0.8	112.1	59.8	397.6	277.8	13.2	4.0	1.7	7.9
Standard deviation (n)	0.3	0.3	0.4	1.8	0.6	0.2	32.2	3.4	83.9	6.0	18.5	1.5	0.2	8.3

APPENDIX 3

Table C1: Total taxonomic groups and species abundant (10^3 cells/L) identified in the Al-Hawizeh marshes during the study period.

Taxa	**Al-Udhaim**	**Um Al-Niaaj**	**Al-Souda north**	**Al-Baydha**	**Al-Souda south**	**Um Al-Warid**	**Lissan Ijerda**	**Majnoon**
Cyanobacteria- Cyanophyceae								
Aphanocapsa sp.1 C.Nägeli	0.0	0.0	0.0	0.1	0.0	9.1	0.0	12.9
Aphanothece sp.1 C.Nägeli	0.0	0.0	0.0	0.0	0.0	0.0	136.0	0.1
(Family) Aphanothecaceae (J.Komárek & Anagnostidis) J.Komárek, J.Kastovsky, J.Mares & J.R.Johansen	83.8	48.9	0.1	0.0	9.1	27.2	0.0	0.0
Chroococcus dispersus (Keissler) Lemmermann	6.8	4.5	0.0	18.1	18.1	0.0	253.5	0.0
Chroococcus minor (Kützing) Nägeli	2.3	2.3	9.2	0.1	0.0	0.0	9.1	18.2
Chroococcus minutus (Kützing) Nägeli	4.6	3.7	0.2	0.0	0.1	0.0	0.0	0.0
Chroococcus turgidus (Kützing) Nägeli	12.9	0.0	25.9	0.0	0.0	0.0	0.1	32.4
(Order) Chroococcales Schaffner	9.1	190.2	81.5	398.4	1449.3	2219.0	0.0	81.5
Dolichospermum sp.	158.0	144.6	41.6	9.6	0.1	27.2	1766.3	22773.8
Cylindrospermum stagnale Bornet & Flahault	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Geitlerinema amphibium (C.Agardh ex Gomont) Anagnostidis	0.0	0.0	0.0	0.0	0.0	0.0	9.1	0.0
Gomphosphaeria aponina Kützing	59.3	4.6	30.2	0.0	0.0	0.0	9.2	183.1
Jaaginema minimum (Gicklhorn) Anagnostidis & Komárek	0.1	41.8	9.3	9.1	0.1	0.0	0.0	18.2
Johanseninema constrictum (Szafer) Hasler, Dvorák & Poulícková	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Johannesbaptistia pellucida (Dickie) W.R.Taylor & Drouet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.9
Leptolyngbya perelegans (Lemmermann) Anagnostidis & Komárek	16.0	133.7	27.3	18.2	54.3	0.0	253.7	833.2
Limnococcus limneticus (Lemmermann) Komárková, Jezberová, O.Komárek & Zapomelová	79.8	1.8	31.3	0.0	0.0	54.4	99.7	302.6
Merismopedia convoluta Brébisson ex Kützing	303.6	190.7	126.9	18.3	9.2	0.1	3831.3	2689.8
Merismopedia elegans A.Braun ex Kützing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.4
Merismopedia glauca (Ehrenberg) Kützing	108.0	0.0	26.0	9.2	0.0	0.0	244.6	1760.9
Merismopedia tenuissima Lemmermann	26.0	58.4	12.9	0.0	0.0	12.9	0.1	285.7
Microcystis aeruginosa (Kützing) Kützing	9.1	29.0	90.6	0.0	0.0	0.0	525.3	190.3
Nostoc sp.1 Vaucher ex Bornet & Flahault	0.0	2.3	0.0	0.0	0.0	0.0	0.0	103.3
Oscillatoria curviceps C.Agardh ex Gomont	2.3	1.8	0.0	0.0	0.0	0.0	0.0	9.1
Oscillatoria geitleriana Elenkin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1
Oscillatoria limosa C.Agardh ex Gomont	6.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oscillatoria sp.1 Vaucher ex Gomont	0.0	6.8	63.4	9.1	18.1	9.1	36.2	0.0
Oscillatoria subbrevis Schmidle	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1
Oscillatoria tenuis C.Agardh ex Gomont	0.0	2.3	0.0	0.0	9.2	0.1	18.2	13.0
Oxynema acuminatum (Gomont) Chatchawan, Komárek, Strunecky, Smarda & Peerapornpisal	0.0	<0.1	0.0	0.0	0.0	0.0	0.0	0.0
Phormidium chalybeum (Mertens ex Gomont) Anagnostidis & Komárek	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.2
Phormidium terebriforme (C.Agardh ex Gomont) Anagnostidis & Komárek	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Planktolyngbya limnetica (Lemmermann) Komárková-Legnerová & Cronberg	104.6	0.0	0.2	18.2	0.0	0.1	9.1	208.3
Pseudanabaena limnetica (Lemmermann) Komárek	490.9	514.1	1048.7	91.0	380.3	67.3	1340.4	8011.4
Spirulina major Kützing ex Gomont	0.2	0.0	0.1	0.2	0.0	9.1	0.0	22.1
Snowella lacustris (Chodat) Komárek & Hindák	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.9
Charophyta - Zygnematophyceae								
Closterium sp.1 Nitzsch ex Ralfs	6.9	3.8	9.1	0.2	0.1	9.1	105.8	72.7
Cosmarium botrytis Meneghini ex Ralfs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1

Taxa	Al-Udhaim	Um Al-Niaaj	Al-Souda north	Al-Baydha	Al-Souda south	Um Al-Warid	Lissan Ijerda	Majnoon
Cosmarium formosulum Hoff	0.0	<0.1	0.0	0.0	0.0	0.0	0.0	0.0
Cosmarium hammeri Reinsch	0.0	0.0	0.0	0.0	0.0	0.0	18.3	18.2
Cosmarium granulatum West	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cosmarium laeve Rabenhorst	0.2	0.0	0.2	0.0	0.1	0.0	0.0	0.1
Cosmarium sp.1 Corda ex Ralfs	15.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cosmarium sp.2 Corda ex Ralfs	1992.6	26.8	3514.5	0.0	18.2	0.0	27.4	207.5
Cosmarium subcostatum Nordstedt	416.9	8.7	18.3	0.0	0.0	0.0	18.2	172.0
Euastrum sp.1 Ehrenberg ex Ralfs	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Gonatozygon kinahanii (W.Archer) Rabenhorst	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
Heimansia pusilla (L.Hilse) Coesel	1444.2	0.0	126.8	0.1	0.1	0.0	0.1	0.0
Mougeotia sp.1 C.Agardh	9.4	16.0	0.3	9.5	9.2	0.0	54.5	22.0
Pleurotaenium sp.1 Nägeli, 1849	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Pleurotaenium trabecula Nägeli	0.1	0.0	0.1	0.1	0.0	0.0	0.1	0.0
Staurastrum natator west	2.3	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Charophyta - Coleochaetophyceae								
Coleochaete scutata Brébisson	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Coleochaete sp.1 Brébisson	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Chlorophyta - Chlorophyceae								
Acutodesmus acuminatus (Lagerheim) P.M.Tsarenko	0.0	4.1	0.0	0.0	0.0	18.3	18.2	31.1
Acutodesmus dimorphus (Turpin) P.M.Tsarenko	0.0	2.3	0.0	0.0	0.0	0.2	9.1	40.2
Ankistrodesmus bibraianus (Reinsch) Korshikov	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.1
Ankistrodesmus falcatus (Corda) Ralfs	270.2	158.7	126.7	54.6	63.4	63.7	2065.0	762.1
Ankistrodesmus fusiformis Corda	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Actinastrum hantzschii Lagerheim	70.3	34.9	0.0	0.0	9.1	0.0	0.0	0.0
Chlamydomonas sp.1 Ehrenberg	0.0	0.0	0.1	0.0	0.0	0.0	27.2	0.0
Coelastrum astroideum De Notaris	133.7	55.9	335.4	18.3	0.1	27.5	244.4	371.5
Coelastrum microporum Nägeli	15.2	2.3	0.1	0.1	0.0	0.0	0.0	31.6
Coelastrum reticulatum (P.A.Dangeard) Senn	2.3	2.3	9.1	0.0	0.0	0.0	9.1	0.1
Crucigenia sp.1 Morren	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Desmodesmus spinosus (Chodat) E.Hegewald	0.0	13.6	0.0	0.0	0.0	0.0	9.1	0.1
Dimorphococcus lunatus A.Braun	2.3	2.3	0.0	0.0	0.0	0.0	9.1	0.0
Kirchneriella irregularis (G.M.Smith) Korshikov	1005.3	8448.1	1983.6	1539.6	1784.4	13206.4	7527.0	4244.6
Kirchneriella obesa (West) West & G.S.West	127.1	262.7	147.5	99.6	126.8	18.1	244.5	18.1
Monoraphidium contortum (Thuret) Komárková-Legnerová	6.8	171.7	199.3	36.4	72.4	27.2	1005.4	4238.9
Monoraphidium sp.1 Komárková-Legnerová	2.3	44.4	18.1	0.0	9.1	0.0	326.0	4999.1
Oedogonium cardiacum Wittrock ex Hirn	0.0	0.0	12.9	0.0	0.0	18.1	0.0	0.0
Oedogonium sp.1 Wittrock ex Hirn	2.3	0.0	0.1	0.0	9.1	18.4	0.0	0.0
Pandorina morum (O.F.Müller) Bory de Saint-Vincent	172.2	59.4	0.1	0.0	9.1	0.0	9.1	0.0
Pseudopediastrum boryanum (Turpin) E.Hegewald	0.0	0.0	0.0	0.0	0.0	0.0	0.0	45.5
Pediastrum duplex Meyen	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Pediastrum tetras var. tetraodon (Corda) Hansgirg	0.0	<0.1	0.0	0.0	0.0	0.0	0.0	0.0
Pseudoschroederia antillarum (Komárek) Hegewald & Schnepf	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scenedesmus acuminatus var. tetradesmoides G.M.Smith	0.0	5.6	0.0	0.0	0.0	18.3	0.0	9.1
Scenedesmus armatus (R.Chodat) R.Chodat	0.0	<0.1	0.0	0.0	0.0	0.0	0.0	0.0
Scenedesmus arcuatus var. platydiscus G.M.Smith	4.6	0.0	0.0	0.0	0.0	0.0	18.3	9.1
Scenedesmus bijuga (Turpin) Lagerheim	197.0	27.0	186.9	0.1	18.3	0.2	54.7	19.4
Scenedesmus bijuga var. alternans (Reinsch) Hansgirg	2.3	0.0	0.1	0.0	0.1	0.0	0.0	0.0
Scenedesmus obliquus (Turpin) Kützing	0.0	0.0	0.0	0.0	0.0	0.0	0.1	9.2

Taxa	Al-Udhaim	Um Al-Niaaj	Al-Souda north	Al-Baydha	Al-Souda south	Um Al-Warid	Lissan Ijerda	Majnoon
Scenedesmus quadricauda (Turpin) Brébisson	534.5	188.4	1005.4	81.6	27.2	117.9	1938.3	3590.7
Scenedesmus sp.1 Meyen	2441.1	2024.9	0.0	9.1	0.0	0.0	0.0	0.0
Schroederia setigera (Schröder) Lemmermann	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Stauridium tetras (Ehrenberg) E.Hegewald	2.3	2.3	0.1	0.0	0.0	0.0	0.0	0.0
Stigeoclonium lubricum (Dillwyn) Kützing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tetraëdron caudatum (Corda) Hansgirg	0.0	0.0	0.0	9.1	0.0	9.1	0.0	0.0
Tetraëdron triangulare Korshikov	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0
Tetrastrum elegans Playfair	0.0	<0.1	0.0	0.0	0.0	0.0	0.0	0.0
Chlorophyta - Trebouxiophyceae								
Botryococcus braunii Kützing	0.0	2.3	0.0	0.0	0.0	9.2	27.2	9.1
Botryococcus protuberans West & G.S.West	0.3	141.8	45.4	0.0	0.0	0.0	1965.6	7384.2
Botryococcus protuberans var. minor G.M.Smith	20.4	183.4	0.0	0.0	0.0	4637.6	443.6	0.0
Chlorella vulgaris Beyerinck [Beijerinck]	0.0	0.0	0.0	0.0	0.0	25.9	0.0	0.0
Crucigeniella saguei Komárek	0.0	0.0	0.0	0.0	0.0	0.0	27.2	0.0
Crucigenia tetrapedia (Kirchner) Kuntze	13.6	32.2	0.2	0.0	27.2	18.2	850.9	335.1
Dictyosphaerium sp.1 Nägeli	22.7	1.8	0.0	0.0	0.0	9.1	9.1	0.0
Micractinium pusillum Fresenius	27.2	0.0	0.0	0.0	0.0	0.0	18.1	0.0
Mucidosphaerium pulchellum (H.C.Wood) C.Bock, Proschold & Krienitz	0.1	0.0	0.0	0.0	0.0	0.0	0.0	12.9
Lagerheimia ciliata var. minor (G.M.Smith) Collins	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0
Oocystis elliptica West	64.9	0.0	120.0	0.0	0.0	0.0	0.0	51.9
Oocystis sp.1 Nägeli ex A.Braun	0.1	2.3	0.1	0.0	0.0	0.1	36.3	135.9
Chlorophyta - Ulvophyceae								
Cladophora sp.1 Kützing	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Rhizoclonium sp.1 Kützing	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0
Ulothrix sp.1 Kützing	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0
Ochrophyta - Xanthophyceae								
Ophiocytium bicuspidatum (Borge) Lemmermann	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Ophiocytium sp.1 (Borge) Lemmermann	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1
Tetraëdriella regularis (Kützing) Fott	86.2	23.2	54.6	18.1	36.3	0.0	0.0	36.4
Ochrophyta - Chrysophyceae								
Dinobryon divergens O.E.Imhof	43.0	18.1	199.4	0.0	0.0	0.0	0.0	0.0
Dinobryon sertularia Ehrenberg	49.2	20.0	18.3	0.1	0.1	0.1	0.1	0.0
Euglenozoa - Euglenophyceae								
Euglena minuta Prescott	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Euglena sp.1 Ehrenberg	2.3	4.6	0.0	27.4	0.1	40.3	18.4	58.5
Lepocinclis sp.1 Perty	0.1	0.0	0.0	9.1	0.2	5.0	54.5	0.0
Phacus pleuronectes f. gigas (Da Cuhna) Popova	0.0	0.0	0.0	0.0	0.0	0.0	9.1	0.1
Phacus longicauda (Ehrenberg) Dujardin	0.0	0.0	0.0	0.0	9.1	0.0	18.2	9.2
Phacus sp.1 Dujardin	355.5	235.1	181.1	54.6	244.5	108.9	425.6	49.4
Trachelomonas sp.1 Ehrenberg	0.0	0.0	0.0	0.0	9.1	18.2	0.1	9.1
Miozoa - Dinophyceae								
Peridiniopsis quadridens (Stein) Bourrelly	6.9	69.1	18.1	0.0	9.1	203.4	63.5	80.3
Peridinium cinctum (O.F.Müller) Ehrenberg	344.2	480.8	461.8	326.1	289.9	860.5	797.1	1331.4
Peridinium sp.1 Ehrenberg	0.1	45.3	9.1	0.1	9.1	18.1	0.1	0.1
Cryptophyta - Cryptophyceae								
Chroomonas nordstedtii Hansgirg	2466.1	1633.7	633.9	371.2	199.4	235.5	2612.0	3378.5
Bacillarophta - Coscinodiscophyceae								
Aulacoseira granulata (Ehrenberg) Simonsen	11.2	14.5	0.0	0.2	44.5	67.0	0.2	33.4
Coscinodiscus lacustris Grunow	0.1	0.0	0.1	0.1	0.0	44.6	0.0	22.2
Coscinodiscus sp.1 Ehrenberg	0.0	5.6	0.1	22.3	11.1	0.0	11.1	0.1

Taxa	Al-Udhaim	Um Al-Niaaj	Al-Souda north	Al-Baydha	Al-Souda south	Um Al-Warid	Lissan Ijerda	Majnoon
Melosira varians C.Agardh	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
Bacillarophyceae								
Achnanthes exigua Grunow	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Achnanthes hungarica (Grunow) Grunow	2.8	0.1	0.0	0.0	0.0	0.3	0.0	0.0
Achnanthes lanceolata (Brébisson ex Kützing) Grunow	0.0	0.0	0.0	11.3	0.0	0.1	0.0	0.1
Achnanthes microcephala (Kützing) Grunow	14.0	45.3	0.1	0.0	0.0	0.0	11.3	0.2
Achnanthes minutissima Kützing	401.8	692.3	222.4	211.9	178.5	185.4	679.2	694.4
Achnanthes lanceolata var. genuina Mayer	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Achnanthes saxonica Krasske ex Hustedt	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Achnanthes sp.1 Bory de Saint-Vincent	0.0	0.0	11.1	0.0	0.1	0.1	0.0	0.0
Achnanthidium pyrenaicum (Hustedt) H.Kobayasi	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
Amphiprora alata (Ehrenberg) Kützing	0.0	31.6	0.2	0.1	0.2	22.5	22.4	356.5
Amphipleura pellucida (Kützing) Kützing	5.6	0.0	0.0	0.0	155.8	0.0	11.1	0.0
Amphora ovalis (Kützing) Kützing	0.0	0.0	0.0	0.0	0.0	11.1	0.0	0.2
Amphora sp.1 C.G.Ehrenberg ex F.T.Kützing	0.1	0.1	0.1	0.0	0.0	0.2	0.0	0.0
Aneumastus stroesei (Østrup) D.G.Mann	0.1	2.8	0.0	0.1	0.2	0.0	33.6	0.1
Anomoeoneis sphaerophora E.Pfitzer	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bacillaria paxillifera (O.F.Müller) T.Marsson	0.2	7.9	0.4	44.6	33.6	45.2	33.5	67.1
Caloneis bacillum (Grunow) Cleve	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.0
Caloneis ventricosa (Ehrenberg) F.Meister	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Cocconeis pediculus Ehrenberg	0.1	18.7	0.2	0.0	0.1	22.8	0.0	0.2
Cocconeis placentula Ehrenberg	17.2	40.4	22.5	22.4	0.5	289.9	0.4	222.8
Cocconeis placentula var. euglypta (Ehrenberg) Grunow	33.9	59.6	25.9	11.6	11.5	537.7	33.6	22.9
Cocconeis placentula var. lineata (Ehrenberg) van Heurck	0.0	2.3	0.1	0.0	0.0	11.3	0.0	0.1
Craticula cuspidata (Kutzing) D.G.Mann	5.8	7.9	0.2	0.1	0.3	0.0	0.3	0.1
Craticula halophila (Grunow) D.G.Mann	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cylindrotheca gracilis (Brébisson ex Kützing) Grunow	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.0
Cymatopleura elliptica (Brébisson) W.Smith	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cymatopleura solea (Brébisson) W.Smith	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Cymbella affinis Kützing	50.9	61.9	0.2	55.8	0.0	55.7	0.1	0.0
Cymbella aspera (Ehrenberg) Cleve	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Cymbella cistula (Ehrenberg) O.Kirchner	11.3	15.8	22.4	11.3	0.2	0.1	0.2	11.1
Cymbella sp.1 C.Agardh	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Cymbella tumida (Brébisson) van Heurck	0.0	0.0	0.0	0.0	0.0	55.9	0.0	0.0
Denticula elegans Kützing	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Denticula sp.1 Kützing	0.0	6.7	0.1	0.0	0.0	0.0	0.0	0.0
Diploneis ovalis (Hilse) Cleve	0.0	4.5	0.0	0.2	0.1	0.1	0.1	89.1
Diploneis pseudovalis Hustedt	22.3	6.8	0.0	22.5	22.5	11.3	0.3	67.1
Epithemia adnata (Kützing) Brébisson	5.6	4.5	0.0	67.0	0.1	0.1	11.3	44.5
Epithemia adnata var. porcellus (Kützing) Patrick	0.1	0.0	0.0	11.4	0.2	0.0	0.1	22.4
Epithemia sorex Kützing	0.0	0.0	0.0	234.1	0.0	0.0	0.0	0.0
Encyonema caespitosum Kützing	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0
Encyonopsis microcephala (Grunow) Krammer	981.9	363.2	752.9	11.6	0.2	0.2	111.7	44.7
Encyonema prostratum (Berkeley) Kützing	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Encyonema perpusillum (Cleve) D.G.Mann	0.3	13.0	0.1	0.2	22.4	0.3	45.1	178.3
Encyonema ventricosum (C.Agardh) Grunow	16.8	3.0	0.0	0.0	0.1	22.5	0.0	0.0
Eunotia bilunaris (Ehrenberg) Schaarschmidt	0.0	0.0	0.0	11.1	0.0	0.0	0.0	0.0
Eunotia formica Ehrenberg	0.0	0.0	0.0	0.0	0.0	0.0	22.5	0.0
Eunotia pectinalis (Kützing) Rabenhorst	0.0	0.0	0.1	11.2	0.1	0.0	0.1	22.2
Eunotia praerupta Ehrenberg	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0

Taxa	**Al-Udhaim**	**Um Al-Niaaj**	**Al-Souda north**	**Al-Baydha**	**Al-Souda south**	**Um Al-Warid**	**Lissan Ijerda**	**Majnoon**
Eunotia sp.1 Ehrenberg	0.0	6.7	0.0	0.1	0.0	0.0	0.0	22.4
Fallacia pygmaea (Kützing) A.J.Stickle & D.G.Mann	0.0	0.0	0.0	0.1	0.0	0.1	0.0	122.5
Gomphonema angustatum (Kützing) Rabenhorst	0.0	0.1	0.1	0.1	55.7	0.0	0.1	0.0
Gomphonema acuminatum var. turris (Ehrenberg) Wolle	5.6	0.0	11.1	0.2	0.0	11.2	0.0	0.0
Gomphonema gracile Ehrenberg	2.9	2.5	11.1	11.5	0.1	14.7	0.0	0.0
Gomphonema gracile f. turris Hustedt	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Gomphonema grunowii R.M.Patrick & Reimer	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Gomphonema intricatum Kützing	2.9	0.0	0.2	0.0	0.0	0.0	0.0	0.4
Gomphonema olivaceum (Hornemann) Brébisson	27.9	27.9	0.1	0.2	0.0	133.8	0.0	0.0
Gomphonema parvulum (Kützing) Kützing	0.2	24.2	0.0	0.4	0.0	114.1	11.1	0.0
Gomphonema tergestinum (Grunow) Fricke	0.0	0.0	0.0	0.1	0.0	0.0	22.3	0.1
Gomphonema truncatum var. turgidum (Ehrenberg) R.M.Patrick	5.7	5.6	0.0	0.2	0.0	0.2	0.0	0.0
Gyrosigma acuminatum (Kützing) Rabenhorst	0.0	0.0	0.1	0.0	0.0	0.2	0.0	11.1
Gyrosigma attenuatum (Kützing) Rabenhorst	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1
Gyrosigma peisone (Grunow) Hustedt	0.0	0.1	0.0	0.0	0.0	0.0	22.4	0.0
Gyrosigma sp.1 Hassall	0.0	7.3	0.0	0.0	0.0	0.0	0.0	0.0
Gyrosigma tenuirostrum (Grunow) Cleve-Euler	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Halamphora coffeiformis (C.Agardh) Levkov	0.2	0.1	0.2	0.0	0.1	44.7	11.3	11.1
Halamphora veneta (Kützing) Levkov	0.0	7.3	0.0	0.3	0.0	22.4	0.3	33.4
Haslea spicula (Hickie) L.Bukhtiyarova	2.9	0.0	0.0	0.0	0.0	0.0	189.5	556.9
Mastogloia braunii Grunow	0.1	0.1	0.0	11.1	0.5	0.0	33.7	11.5
Mastogloia elliptica (C.Agardh) Cleve	14.3	10.7	0.2	44.5	0.2	0.0	22.7	0.1
Mastogloia danseyi (Thwaites) Thwaites ex W.Smith	34.9	36.3	77.2	55.9	156.0	0.1	122.5	58.5
Mastogloia lacustris (Grunow) Grunow	0.0	<0.1	0.0	0.0	0.0	0.0	0.0	0.0
Mastogloia smithii Thwaites ex W.Smith	0.0	2.8	0.0	0.0	0.2	0.0	0.2	0.1
Mastogloia smithii var. amphicephala Grunow	0.1	2.8	0.0	0.0	11.1	0.0	0.0	0.4
Mayamaea atomus (Kützing) Lange-Bertalot	0.0	2.3	0.0	0.0	0.0	33.4	0.1	11.1
Navicula capitatoradiata Germain	0.0	0.1	0.0	11.1	0.1	0.0	0.0	0.1
Navicula cincta (Ehrenberg) Ralfs	0.0	36.6	0.0	0.0	0.0	15.1	0.0	0.0
Navicula cryptocephala Kützing	17.0	27.4	0.5	0.3	0.3	25.7	0.2	44.8
Navicula cryptocephala f. minuta J.B.Petersen	0.0	<0.1	0.0	0.0	0.0	0.0	0.0	0.0
Navicula cryptocephala var. veneta (Kützing) Rabenhorst	2.9	2.5	0.4	33.5	0.2	11.4	33.6	311.8
Navicula exilis Kützing	0.3	130.8	144.9	0.0	0.1	0.0	178.3	55.7
Navicula inflata Donkin	0.0	0.0	7.8	0.0	0.0	0.0	0.0	0.0
Navicula radiosa Kützing	142.5	90.0	111.7	11.2	89.2	0.1	0.1	0.0
Navicula rhynchocephala Kützing	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
Navicula sp.1 Bory de Saint-Vincent	0.0	0.0	0.0	0.0	0.0	0.0	0.0	55.7
Navicula tripunctata (O.F.Müller) Bory de Saint-Vincent	19.6	14.0	22.5	0.0	0.0	267.4	11.4	0.1
Neidium iridis (Ehrenberg) Cleve	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia acicularis (Kützing) W.Smith	0.0	2.3	0.1	0.0	0.0	0.2	22.3	568.0
Nitzschia amphibia Grunow	0.1	16.9	0.1	0.0	0.2	14.6	0.0	0.1
Nitzschia clausii Hantzsch	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0
Nitzschia constricta (Kützing) Ralfs	0.0	0.1	11.4	0.1	0.0	0.1	0.0	0.1
Nitzschia dissipata (Kützing) Rabenhorst	0.0	2.8	0.0	0.0	0.0	11.5	0.0	0.0
Nitzschia fasciculata (Grunow) Grunow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Nitzschia fonticola (Grunow) Grunow	0.0	0.0	0.0	0.0	0.0	0.0	0.1	33.4
Nitzschia frustulum (Kützing) Grunow	30.7	47.6	22.3	0.0	22.3	28.0	0.0	22.7
Nitzschia frustulum var. perminuta Grunow	0.0	0.1	0.0	0.0	0.0	590.1	0.0	0.0
Nitzschia frustulum var. perpusilla (Rabenhorst) Van Heurck	0.0	0.0	0.0	0.0	0.0	11.1	0.0	11.1

Taxa	**Al-Udhaim**	**Um Al-Niaaj**	**Al-Souda north**	**Al-Baydha**	**Al-Souda south**	**Um Al-Warid**	**Lissan Ijerda**	**Majnoon**
Nitzschia gracilis Hantzsch	30.7	27.1	41.5	11.5	33.4	44.9	1425.1	12377.4
Nitzschia hantzschiana Rabenhorst	0.0	0.0	0.0	0.0	0.0	0.0	0.0	44.5
Nitzschia inconspicua Grunow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Nitzschia intermedia Hantzsch	0.0	0.0	0.0	0.0	0.0	0.0	0.0	55.6
Nitzschia longissima (Brébisson) Ralfs	14.1	43.3	67.1	44.5	0.1	123.1	55.9	2246.9
Nitzschia microcephala Grunow	0.1	2.2	0.3	22.5	0.1	22.2	0.7	623.1
Nitzschia obtusa W.Smith	2.8	0.0	0.1	0.0	22.4	0.1	0.1	0.0
Nitzschia palea (Kützing) W.Smith	181.5	686.5	321.9	445.5	389.8	1783.6	846.1	18670.4
Nitzschia punctata var. coarctata (Grunow) Hustedt	0.0	0.0	0.0	0.0	0.0	0.1	0.4	278.6
Nitzschia sigma (Kützing) W.Smith	0.1	0.0	0.1	0.0	0.6	22.4	0.0	22.5
Nitzschia sigma var. rigidula (Peragallo & Peragallo) Grunow	0.0	0.0	0.0	0.0	11.3	0.0	0.0	0.0
Nitzschia sigmoidea (Nitzsch) W.Smith	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.0
Nitzschia tryblionella Hantzsch	0.0	0.0	0.0	0.0	0.0	0.1	0.0	178.4
Nitzschia tryblionella var. levidensis (W.Smith) Grunow	0.0	0.0	0.0	0.0	0.0	11.2	0.0	0.0
Nitzschia tryblionella var. victoriae (Grunow) Grunow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.2
Parlibellus crucicula (W.Smith) Witkowski, Lange-Bertalot & Metzeltin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1
Pinnularia acutobrebissonii Kulikovskiy, Lange-Bertalot & Metzeltin	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0
Pinnularia microstauron (Ehrenberg) Cleve	0.0	11.1	0.0	22.3	0.0	0.3	0.0	11.1
Pinnularia sp.1 Ehrenberg	<0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Placoneis elginensis (Gregory) E.J.Cox	0.0	<0.1	0.0	0.0	0.0	0.0	0.0	0.0
Pleurosigma angulatum (Queckett) W.Smith	0.0	0.0	0.0	0.0	0.0	0.1	0.0	66.7
Pleurosigma salinarum (Grunow) Grunow	0.0	0.0	0.0	0.0	0.0	0.1	0.0	44.8
Pleurosigma sp.1 W.Smith	0.0	0.0	0.0	0.0	0.0	0.1	0.1	22.3
Rhoicosphenia abbreviata (C.Agardh) Lange-Bertalot	5.6	13.4	0.0	0.1	0.1	22.7	0.1	0.3
Rhopalodia gibba (Ehrenberg) Otto Müller	14.4	18.8	0.0	45.2	22.5	0.1	34.0	412.8
Rhopalodia gibba var. ventricosa (Kützing) H.Peragallo & M.Peragallo	14.5	0.0	0.1	0.1	0.0	0.0	11.2	0.0
Rhopalodia musculus (Kützing) Otto Müller	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Sellaphora pupula (Kützing) Mereschkovsky	0.0	13.9	11.1	0.0	0.0	0.1	0.0	0.0
Stauroneis fluminea R.M.Patrick & Freese	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Surirella capronii Brébisson ex F.Kitton	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Surirella minuta Brébisson	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.2
Surirella ovalis Brébisson	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Surirella ovata var. africana Cholnoky	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Tryblionella granulata (Grunow) D.G.Mann	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1
Tryblionella hungarica (Grunow) Frenguelli	0.0	0.0	0.0	0.0	0.0	22.4	0.2	0.0
Tryblionella scalaris (Ehrenberg) P.Siver & P.B.Hamilton	2.8	0.0	0.2	22.5	0.4	0.0	0.1	184.3
Bacillarophta - Mediophyceae								
Chaetoceros sp.1 Ehrenberg	0.0	0.0	0.0	0.0	0.0	0.1	100.4	133.7
Cyclotella atomus Hustedt	166.4	974.6	41.3	44.5	22.5	2233.3	812.8	158.5
Cyclotella kuetzingiana Thwaites	33.6	14.0	0.1	44.5	0.2	0.1	22.5	89.2
Cyclotella meneghiniana Kützing	206.3	9380.6	167.3	200.8	278.3	7366.2	901.8	1311.0
Cyclotella ocellata-kutzingiana	0.0	409.6	55.6	0.0	0.1	879.6	44.6	233.7
Cyclotella radiosa (Grunow) Lemmermann	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Cyclotella stelligera Cleve & Grunow	0.0	0.0	0.0	0.0	0.0	0.0	33.4	33.4
Cyclotella striata (Kützing) Grunow	0.0	0.1	0.0	0.1	0.1	0.1	11.2	25.8
Stephanodiscus astraea (Ehrenberg) Grunow	0.0	93.6	0.0	0.0	0.0	144.7	0.0	11.2
Bacillarophta - Fragilariophyceae								
Ctenophora pulchella (Ralfs ex Kützing) D.M.Williams & Round	0.0	36.2	0.1	100.2	0.0	0.0	11.2	11.1

Taxa	Al-Udhaim	Um Al-Niaaj	Al-Souda north	Al-Baydha	Al-Souda south	Um Al-Warid	Lissan Ijerda	Majnoon
Diatoma tenuis C.Agardh	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Fragilaria acus (Kützing) Lange-Bertalot	51.5	258.5	67.0	44.8	100.1	44.5	22.6	2026.4
Fragilaria brevistriata Grunow	0.0	0.0	0.2	0.0	0.0	0.1	0.0	55.9
Fragilaria capucina var. vaucheriae (Kützing) Lange-Bertalot	2.8	46.0	43.9	144.9	33.6	33.8	89.5	467.6
Fragilaria construens (Ehrenberg) Grunow	0.0	0.0	0.0	0.2	0.0	11.2	0.0	0.2
Fragilaria fasciculata (C.Agardh) Lange-Bertalot	0.1	0.0	36.4	0.0	0.1	0.1	0.1	0.0
Gomphoneis olivacea (Hornemann) P.Dawson ex R.Ross & P.A.Sims	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Hantzschia amphioxys (Ehrenberg) Grunow	0.2	9.6	14.5	0.1	0.1	0.0	0.0	14.5
Synedra acus var. angustissima (Grunow) van Heurck	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
Ulnaria biceps (Kützing) P.Compère	0.0	11.2	14.6	22.4	0.1	0.2	33.4	0.0
Ulnaria capitata (Ehrenberg) P.Compère	0.1	4.5	0.0	0.0	0.1	0.0	0.1	0.0
Ulnaria oxyrhynchus (Kützing) M.Aboal	0.0	24.7	0.0	0.0	0.0	11.3	0.0	0.0
Ulnaria ulna (Nitzsch) P.Compère	188.7	452.3	78.2	178.2	56.0	100.7	133.6	111.3

Table C2: Monthly abundance (cells/ml) of the identified phytoplankton classes in Al-Hawizeh marshes.

	Apr-06	May-06	Jun-06	Jul-06	Aug-06	Sep-06	Oct-06	Nov-06	Dec-06	Jan-07	Feb-08	Aug-08
Al-Udhaim												
Cyanobacteria- Cyanophyceae	18	54	102	5	227	245	195	93	39	54	155	298
Charophyta - Zygnematophyceaee	0	0	7	18	403	1526	161	95	111	113	1454	0
Charophyta - Coleochaetophyceae	0	0	0	0	0	0	0	0	0	0	0	0
Chlorophyta - Chlorophyceae	462	125	73	32	143	2799	720	102	59	9	82	389
Chlorophyta - Trebouxiophyceae	0	0	34	9	23	9	2	5	2	0	0	65
Chlorophyta - Ulvophyceae	0	0	0	0	0	0	0	0	0	0	0	0
Ochrophyta - Xanthophyceae	0	5	0	2	11	14	23	18	9	5	0	0
Ochrophyta - Chrysophyceae	0	43	0	0	0	0	9	0	0	0	27	13
Euglenozoa - Euglenophyceae	263	27	7	0	0	2	0	59	0	0	0	0
Miozoa - Dinophyceae	54	43	18	16	16	106	75	18	2	2	0	0
Cryptophyta - Cryptophyceae	1033	84	256	2	2	2	7	127	16	32	553	353
Bacillarophta - Coscinodiscophyceae	0	0	0	0	0	0	0	0	0	0	11	0
Bacillarophta - Bacillarophyceae	90	229	107	79	59	134	95	362	212	579	146	58
Bacillarophta - Mediophyceae	0	81	8	17	17	17	3	31	6	28	156	44
Bacillarophta - Fragilariophyceae	0	17	45	61	25	6	50	3	6	31	0	0
Um Al-Niaaj												
Cyanobacteria- Cyanophyceae	112	231	310	125	214	97	58	114	22	11	9	78
Charophyta - Zygnematophyceaee	4	7	0	5	7	18	11	5	0	0	0	0
Charophyta - Coleochaetophyceae	0	0	0	0	0	0	0	0	0	0	0	0
Chlorophyta - Chlorophyceae	1471	3014	2013	942	911	1882	553	268	89	44	326	0
Chlorophyta - Trebouxiophyceae	6	11	140	77	103	23	2	2	0	0	0	0
Chlorophyta - Ulvophyceae	0	2	0	0	0	0	0	0	0	0	0	0
Ochrophyta - Xanthophyceae	4	2	0	2	2	7	2	2	2	0	0	0
Ochrophyta - Chrysophyceae	0	18	0	0	0	0	20	0	0	0	0	0
Euglenozoa - Euglenophyceae	33	136	25	5	2	0	0	2	34	4	0	0
Miozoa - Dinophyceae	44	127	25	54	27	63	121	27	4	31	45	26
Cryptophyta - Cryptophyceae	270	100	27	2	0	32	190	413	187	413	0	0
Bacillarophta - Coscinodiscophyceae	0	0	0	0	0	11	0	0	0	9	0	0
Bacillarophta - Bacillarophyceae	193	251	153	179	130	51	36	88	96	818	80	640
Bacillarophta - Mediophyceae	11	8	354	98	62	31	22	65	5	254	9898	66
Bacillarophta - Fragilariophyceae	31	348	53	75	27	6	40	149	25	22	45	22
Al-Souda north												
Cyanobacteria- Cyanophyceae	879	136	18	0	45	73	190	54	55	18	1	157
Charophyta - Zygnematophyceaee	9	0	0	0	2065	852	172	45	272	127	127	0
Charophyta - Coleochaetophyceae	0	0	0	0	0	0	0	0	0	0	0	0
Chlorophyta - Chlorophyceae	390	1476	109	0	64	1024	426	91	82	0	118	247
Chlorophyta - Trebouxiophyceae	0	27	0	0	0	0	0	0	0	0	18	120
Chlorophyta - Ulvophyceae	0	0	0	0	0	0	0	0	0	0	0	0
Ochrophyta - Xanthophyceae	0	9	9	0	0	0	18	9	0	9	0	0
Ochrophyta - Chrysophyceae	0	199	0	0	0	0	9	0	0	0	9	0
Euglenozoa - Euglenophyceae	9	54	45	0	0	0	0	54	9	9	0	0
Miozoa - Dinophyceae	54	54	36	0	45	0	290	0	0	0	9	0
Cryptophyta - Cryptophyceae	118	9	27	18	0	0	0	154	226	0	82	0
Bacillarophta - Coscinodiscophyceae	0	0	0	0	0	0	0	0	0	0	0	0
Bacillarophta - Bacillarophyceae	246	190	79	0	67	90	178	223	480	134	102	135
Bacillarophta - Mediophyceae	56	56	33	0	11	0	11	56	11	22	0	8
Bacillarophta - Fragilariophyceae	45	56	0	0	22	0	0	11	11	0	0	109

	Apr-06	May-06	Jun-06	Jul-06	Aug-06	Sep-06	Oct-06	Nov-06	Dec-06	Jan-07	Feb-08	Aug-08
Um Al-Warid												
Cyanobacteria- Cyanophyceae	335	1875	18	91	0	36	9	18	18	0	0	35
Charophyta - Zygnematophyceaee	0	9	0	0	0	0	0	0	0	0	0	0
Charophyta - Coleochaetophyceae	0	0	0	0	0	0	0	0	0	0	0	0
Chlorophyta - Chlorophyceae	1314	7265	118	1975	18	1332	698	73	0	725	27	0
Chlorophyta - Trebouxiophyceae	0	0	9	63	897	1721	1975	0	0	0	9	26
Chlorophyta - Ulvophyceae	0	0	0	0	0	0	0	0	0	0	0	0
Ochrophyta - Xanthophyceae	0	0	0	0	0	0	0	0	0	0	0	0
Ochrophyta - Chrysophyceae	0	0	0	0	0	0	0	0	0	0	0	0
Euglenozoa - Euglenophyceae	9	27	64	9	0	0	18	18	0	9	0	18
Miozoa - Dinophyceae	118	27	45	145	0	317	154	9	0	45	18	203
Cryptophyta - Cryptophyceae	0	0	118	0	0	0	0	36	0	0	82	0
Bacillarophta - Coscinodiscophyceae	0	0	45	0	0	0	0	0	67	0	0	0
Bacillarophta - Bacillarophyceae	747	780	525	313	0	279	357	46	635	190	136	670
Bacillarophta - Mediophyceae	512	5010	412	902	0	278	334	78	111	457	2450	80
Bacillarophta - Fragilariophyceae	56	23	0	11	0	0	67	11	0	11	23	0
Al-Baydha												
Cyanobacteria- Cyanophyceae	317	9	172	36	27	0	18	9	9	0	1	
Charophyta - Zygnematophyceaee	0	0	0	0	0	0	0	0	9	0	0	
Charophyta - Coleochaetophyceae	0	0	0	0	0	0	0	0	0	0	0	
Chlorophyta - Chlorophyceae	1150	127	36	54	217	55	72	0	0	36	100	
Chlorophyta - Trebouxiophyceae	0	0	0	0	0	0	0	0	0	0	0	
Chlorophyta - Ulvophyceae	0	0	0	0	0	0	0	0	0	0	0	
Ochrophyta - Xanthophyceae	0	0	0	0	0	0	18	0	0	0	0	
Ochrophyta - Chrysophyceae	0	0	0	0	0	0	0	0	0	0	0	
Euglenozoa - Euglenophyceae	18	9	9	9	9	0	27	0	9	0	0	
Miozoa - Dinophyceae	27	18	27	45	45	118	45	0	0	0	0	
Cryptophyta - Cryptophyceae	36	0	63	0	0	0	0	136	36	91	9	
Bacillarophta - Coscinodiscophyceae	0	22	0	0	0	0	0	0	0	0	0	
Bacillarophta - Bacillarophyceae	157	157	201	157	145	68	101	35	212	68	235	
Bacillarophta - Mediophyceae	11	45	22	11	11	0	0	22	11	0	156	
Bacillarophta - Fragilariophyceae	67	11	100	89	67	45	34	33	0	23	23	
Al-Souda south												
Cyanobacteria- Cyanophyceae	1558	45	109	0	63	63	100	9	0	0	1	
Charophyta - Zygnematophyceaee	9	9	0	0	9	0	0	0	0	0	0	
Charophyta - Coleochaetophyceae	0	0	0	0	0	0	0	0	0	0	0	
Chlorophyta - Chlorophyceae	1105	299	380	9	54	91	45	0	9	9	127	
Chlorophyta - Trebouxiophyceae	0	27	0	0	0	0	0	0	0	0	0	
Chlorophyta - Ulvophyceae	0	0	0	0	0	0	0	0	0	0	0	
Ochrophyta - Xanthophyceae	0	0	0	0	0	0	36	0	0	0	0	
Ochrophyta - Chrysophyceae	0	0	0	0	0	0	0	0	0	0	0	
Euglenozoa - Euglenophyceae	36	82	118	0	9	0	0	18	0	0	0	
Miozoa - Dinophyceae	36	9	54	0	100	18	45	18	0	18	9	
Cryptophyta - Cryptophyceae	36	0	18	54	0	9	0	0	0	9	73	
Bacillarophta - Coscinodiscophyceae	45	11	0	0	0	0	0	0	0	0	0	
Bacillarophta - Bacillarophyceae	469	203	212	11	46	23	23	57	101	56	46	
Bacillarophta - Mediophyceae	33	11	22	0	78	0	11	22	45	22	56	
Bacillarophta - Fragilariophyceae	0	33	11	0	11	0	11	0	45	34	45	
Lissan Ijerda												
Cyanobacteria- Cyanophyceae	190	942	290	869	1975	1639	1694	933	0	9	0	
Charophyta - Zygnematophyceaee	0	82	18	52	18	27	18	0	0	0	10	

	Apr-06	May-06	Jun-06	Jul-06	Aug-06	Sep-06	Oct-06	Nov-06	Dec-06	Jan-07	Feb-08	Aug-08
Charophyta - Coleochaetophyceae	0	0	0	0	0	0	0	0	0	0	0	
Chlorophyta - Chlorophyceae	806	4502	299	1223	2817	1015	1802	462	317	9	263	
Chlorophyta - Trebouxiophyceae	272	1576	254	100	217	190	571	163	36	0	0	
Chlorophyta - Ulvophyceae	0	0	0	0	0	0	0	0	0	0	0	
Ochrophyta - Xanthophyceae	0	0	0	0	0	0	0	0	0	0	0	
Ochrophyta - Chrysophyceae	0	0	0	0	0	0	0	0	0	0	0	
Euglenozoa - Euglenophyceae	36	145	0	37	9	45	9	82	154	9	0	
Miozoa - Dinophyceae	63	281	0	0	73	308	63	45	27	0	0	
Cryptophyta - Cryptophyceae	1957	109	27	18	0	18	82	27	163	103	109	
Bacillarophta - Coscinodiscophyceae	0	0	0	0	0	0	0	11	0	0	0	
Bacillarophta - Bacillarophyceae	57	1326	156	691	479	491	224	179	157	67	247	
Bacillarophta - Mediophyceae	167	167	45	134	134	568	412	189	67	22	22	
Bacillarophta - Fragilariophyceae	0	11	0	0	0	56	11	34	11	11	156	
Majnoon												
Cyanobacteria- Cyanophyceae	317	915	6386	7400	8234	4719	4755	381	969	580	0	2962
Charophyta - Zygnematophyceaee	36	163	91	0	18	0	0	0	36	18	0	130
Charophyta - Coleochaetophyceae	0	0	0	0	0	0	0	0	0	0	0	0
Chlorophyta - Chlorophyceae	1758	2600	7237	154	2164	897	1467	1594	45	317	46	142
Chlorophyta - Trebouxiophyceae	5788	1594	390	0	9	18	9	0	0	0	0	121
Chlorophyta - Ulvophyceae	0	0	0	0	0	0	0	0	0	0	0	0
Ochrophyta - Xanthophyceae	0	0	27	0	9	0	0	0	0	9	0	0
Ochrophyta - Chrysophyceae	0	0	0	0	0	0	0	0	0	0	0	0
Euglenozoa - Euglenophyceae	18	18	27	18	0	0	0	0	9	9	0	26
Miozoa - Dinophyceae	82	63	82	27	317	73	0	0	263	480	0	26
Cryptophyta - Cryptophyceae	127	136	0	0	0	91	63	688	1630	634	9	0
Bacillarophta - Coscinodiscophyceae	0	0	0	11	0	0	0	22	11	0	11	0
Bacillarophta - Bacillarophyceae	6648	6636	5411	5700	1816	1304	3819	3630	1738	1036	1093	242
Bacillarophta - Mediophyceae	278	278	223	89	134	0	78	134	100	89	312	282
Bacillarophta - Fragilariophyceae	89	123	167	78	45	22	11	11	56	2037	34	15