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BioRisk

Biodiversity & Ecosystem Risk Assessment

ENVIRONMENT, BIODIVERSITY AND CONSERVATION IN THE MIDDLE EAST

Proceedings of the First Middle Eastern Biodiversity Congress, Aqaba, Jordan, 20–23 October 2008

Edited by Friedhelm Krupp, Lytton J. Musselman, Mohammed M.A. Kotb, Ilka Weidig

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EDITORIAL

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The effects of climate change on biodiversity: Pressing issues and research priorities

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On a global scale, the Middle East is the only transition zone between three major biogeographic units, the Palaearctic, Afrotropical and Oriental Realms, resulting in an outstanding biogeographic significance and unique biological diversity. Biodiversity, which is part of our life-support system, is of particular ecological, economic, spiritual, cultural, and aesthetic importance. The countries in the Middle East have ratified the United Nations Convention on Biological Diversity, with obligations to document and conserve the floras and faunas on their territories. In recent years, numerous projects focusing on sustainable use and conservation of biological diversity have been initiated. However, the scientific and academic baselines are often lacking. The "Middle Eastern Biodiversity Network" (MEBN), founded in 2006 by six universities and research institutes in Iran, Jordan, Germany, Lebanon and Yemen was designed to fill this gap.

The overall goal of the MEBN is to strengthen, within a multi-facetted network, the capacity of countries throughout the Middle East in documenting and analysing the Region's biodiversity, promoting sustainable resource use, and conservation. Given the transboundary nature of biodiversity issues a regional approach is required. Consequently, networking is the preferred solution. The results of baseline research carried out in the framework of the MEBN are of utmost importance for many applied fields, such as conservation, coastal zone management, fisheries management, agriculture, and forestry. It is imperative that these results be available to peers, decision makers, and the general public. A wide range of activities are carried out in the framework of the Network, including regional capacity building in establishing professionally managed nature museums, developing university curricula in biodiversity, conducting scientific research, and organising workshops and conferences on Middle Eastern biodiversity. Finally, a key task is translating biodiversity research into conservation and sustainable development.

The "First Middle Eastern Biodiversity Congress" was held in Aqaba, Jordan from 20 to 23 October 2008. However, strictly speaking, this was not the first conference of its kind. A symposium on Biodiversity in the Middle East was organised in 1951 by the late Professors H.A.F. Gohar, K. Kosswig and H. Steinitz in Istanbul, Turkey. In 1985, a second "Symposium on the Fauna and Zoogeography of the Middle East" was held in Mainz, Germany, organised by R. Kinzelbach, F. Krupp and W. Schneider. Many colleagues, who participated in that conference 23 years ago, attended the Aqaba Congress. The 40 participants of the Mainz Symposium came up with visions, plans, and recommendations for future activities to promote regional scientific collaboration, and the conference in Aqaba offered an excellent opportunity to evaluate what has been achieved and to decide where to go from here. The community of scientists involved in biodiversity research, education, and conservation has grown significantly. More than 500 colleagues registered for the Aqaba Congress and more than 300 attended (Fig. 1).

Besides following up on themes addressed in the past, emerging issues received attention, particularly climate change, which is considered one of the most pressing global problems of mankind. Reliable scenarios for pathways of future climate change are available, though little is known about the consequences. The biosphere is reacting to climate change and the effects will be highly complex, affecting speciation and extinction rates, geographic distribution of species, composition and functioning of ecosystems, ecophenotypic adaptation, and biogeochemical cycles. All these processes are still very poorly understood. Since humans are part of and directly depend on biodiversity it is essential that biologists now join forces to get a better understanding of what our living world will look like in the near future. Thus, in Aqaba a specialised symposium discussed the effects of climate change on biodiversity, identifying the most pressing issues and research priorities in the Region.

The Middle East is plagued by conflicts, which have major impacts on biodiversity and the present situation in the Region is not conducive to cooperation across national boundaries. Being aware of the importance of a regional dialogue, the organisers of the Aqaba Congress took up a challenge in bringing together scientists from all parts of the Region. Given the ecological and economic importance of biodiversity research, education and conservation – above all in the light of climate change – we as biodiversity researchers must find ways to overcome present barriers to fulfilling our societal duties, building on the great potential that science offers for bridging gaps. The very survival of the Region's flora and fauna is at stake, and we are still far away from viable solutions to these pressing problems. The participation of scientists from Europe, Asia, Africa, the Americas and Australia underline the global significance of Middle Eastern biodiversity and opportunities for international cooperation.

This special issue of "BioRisk – Biodiversity and Ecosystem Risk Assessment" contains 15 papers presented during the First Middle Eastern Biodiversity Congress, addressing a wide range of themes ranging from plant and animal biodiversity, ecology and conservation, impact of development, and the effects of climate change, to biodiversity networking in other parts of the world. Out of 32 authors contributing to this issue, 23 are from the Region, while nine are from Europe and North America. In the proceedings of the Mainz Symposium (Krupp et al. 1987), only eight out of 28 authors were from the Middle East. This is a clear sign of the growing attention biodiversity research is receiving in the Region. Papers addressing systematic zoology are included in a special issue of ZooKeys, which is being published simultaneously.

The First Middle Eastern Biodiversity Congress was jointly organised by the Senckenberg Research Institute and Museum of Nature, Frankfurt am Main, Germany; and the Marine Science Station, Aqaba, Jordan, two institutions with a long history of collaboration in biodiversity research, education, and conservation. Many organisations and individuals have supported the conference, too many to be mentioned by name. We are particularly grateful to the German Academic Exchange Service (DAAD) for financially supporting the MEBN during its first three years of existence and for making this Congress a reality. Several Jordanian organisations, institutions and companies financially supported the Congress: The Middle East Science Fund, the University of Jordan, Yarmouk University, the Aqaba Special Economic Zone Authority, the Jordan Higher Council for Science and Technology, Ayla Resort, the Jordan Commercial Bank, and the Aqaba Development Corporation. We are most grateful to all member institutions of the MEBN, our partners in organising the Congress and the commercial sponsors. Our colleagues in Aqaba and Frankfurt, particularly Maroof Khalaf, Fuad Al-Horani, Riyad Manasrah, Saber Al-Rosan, Nadia Manasfi, Eike Neubert and Matthias Schneider put a tremendous amount of skilful effort into organising this conference. Our thanks are also due to the authors contributing to this issue, the referees who reviewed the papers, and to Pensoft Publishers for a very fruitful collaboration. The publication of this special issue of BioRisk was financially supported by the Biodiversity and Climate Research Centre (BiK-F), Frankfurt am Main, which is part of the research funding programme "LOEWE – Landes-Offensive zur Entwicklung Wissenschaftlich-ökonomischer Exzellenz" of the Ministry of Higher Education, Research and Arts, State of Hesse, Germany.

Reference

Krupp F, Schneider W, Kinzelbach R (Eds) (1987) Proceedings of the Symposium on the Fauna and Zoogeography of the Middle East, Mainz 1985. Beihefte zum Tübinger Atlas des Vorderen Orients A 28: 338 pp. Ludwig Reichert, Wiesbaden.

Figure 1. Participants of the First Middle Eastern Biodiversity Congress in Aqaba, Jordan (photo Yasser Geneid, 23 October 2008).

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REVIEW ARTICLE

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Tethys returns to the Mediterranean: Success and limits of tropical re-colonization

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Abstract

Many thousands of tropical species have been settling in the Mediterranean during the last decades. This is the result of congruence between the present Climate Optimum, which is expressed in the warming of the sea and the opening of the contact with the Indo-pacific realm through the Suez Canal and a renewed entry through the Straits of Gibraltar. A historical review shows that tropical biota survived in the Mediterranean till the end of the Pliocene Climate Optimum and that presently we are witnessing a re-colonization of the Mediterranean by Tethyan descendants, rather than an invasion by harmful alien species as happens elsewhere. The limits of this resettling as witnessed today are discussed.

Keywords

Lessepsian migration, invasive species, climate change, Mediterranean biodiversity, Tethys

Introduction

Time is ripe for a historical appreciation of the impressive biogeographical events that brought into the Mediterranean thousands of tropical species during the last decades. As usual in such cases, several lines of thought and different fields of knowledge have to be called in. In order to better understand the broader significance of the dramatic changes in the biodiversity of the Mediterranean, I shall focus on those taxa, which have fossil documentation and temperature tolerance data to juxtapose with our recent and paleoclimatology knowledge.

The tropical Cretaceous-Neogene Tethys Ocean (Fig.1), is often known in its Mediterranean section, also as the Eocene "Nummulite Sea". It was characterized by an abundance of the large, small-coin sized benthic Nummulitidae, symbiont-bearing Foraminifera. They are best seen in the stones of the pyramids of Egypt. *Heterostegina*, the last surviving genus of this family, disappeared from the Mediterranean, some five million years ago. The recent discovery that *Heterostegina depressa* is again abundantly represented in the sandy sediments along the Israeli coast of the Mediterranean, together with other symbiont-bearing Foraminifera (Hyams et al. 2002) conferred the real historical dimension to the biodiversity shift happening presently in the Mediterranean.

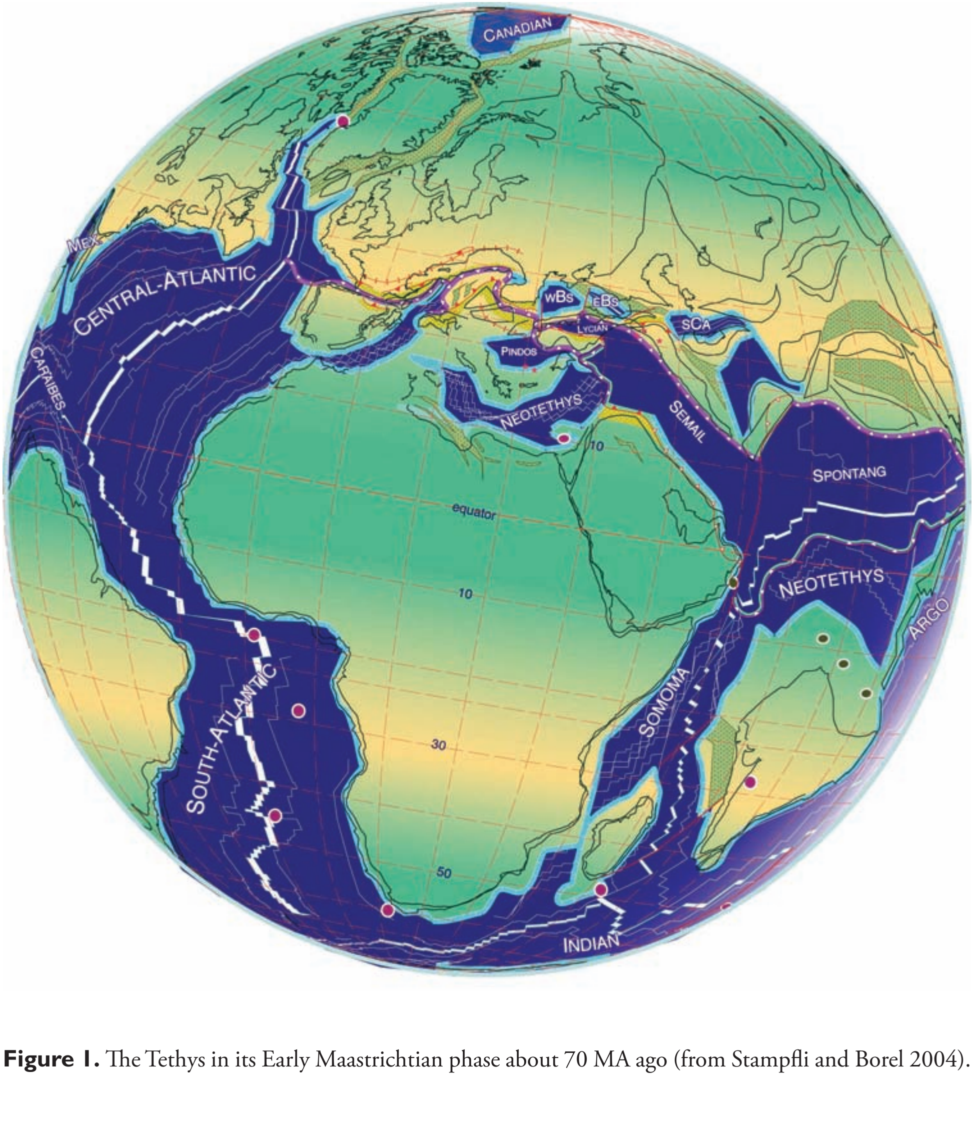

Figure 1. The Tethys in its Early Maastrichtian phase about 70 MA ago (from Stampfli and Borel 2004).

The Mediterranean is possibly and partly reverting to its original tropical warm-water biological condition, which was only relatively recently interrupted by the start of the glaciation cycles 2.58 million years ago. In a geological perspective, what is happening now, may be considered a return to normal conditions, possibly a normalization event.

Messinian survival

Although the circum-tropical Tethys Ocean ceased to exist when the Mediterranean basin finally lost its contact with the nascent Indian Ocean 13.6 million years ago in the area of the Mesopotamian trough (Harzhauser et al. 2007), its fauna continued to be tropical even when it started to be restricted at the base of the Messinian phase of the Miocene 7.1 million years ago. The climax of the Messinian salinity crisis with huge halite deposits lasted only between 5.6 and 5.5 million years ago and the definitive opening of the Mediterranean to the Atlantic and implicitly the start of the Pliocene is dated at 5.32 million years ago.

The original idea, which is still maintained by many, that during the Messinian high salinity crisis all the marine life of the Mediterranean was exterminated, is not correct. Marine life survived into the Pliocene in the near-shore environments, like those of southern Spain, from where *Porites* reefs are still reported, together with a variety of irregular tropical sea urchins (Esteban 1979/1980; Néraudeau et al. 2001). A variety of tropical fish were reported from the Messinian of Italy, among them the round herring *Spratelloides*, the razor fish *Centriscus* (Fig. 2) and the cornet fish *Fistularia* (Sorbini and Tirapelle Rancan 1980, Sorbini 1988).

The classical Tethyan relic, a Messinian survivor, is the dominant and characteristic Mediterranean seagrass *Posidonia oceanica*, whose congeners are known only from Australia, but it did not leave any fossil evidence prior to a putative one in the lower Pliocene (Aguirre et al. 2006)

The problem of the contact with the Red Sea

While the Mediterranean lost its contact with the Indian Ocean through the Mesopotamian through, the nascent Red Sea was its southern gulf. The northern Red Sea had also its period of halite deposition, but it occurred earlier than in the Mediterranean and the Messinian there was characterized by marine deposits (Griffin 2002). At some stage, the rifting process, which opened the Red Sea in the Eocene, turned eastward forming the deep Gulf of Aqaba. The Gulf of Suez remained shallow. A tectonic doming movement, sometime in the early Pliocene, lifted up the Isthmus of Suez, which ever since separates the Mediterranean from the Red Sea. Today the maximum elevation on the Isthmus is 23 m.

The exact date of the opening of the Red Sea to the Indian Ocean is unknown. Admittedly, it happened also at the start of the Pliocene, but if it was still in time for some

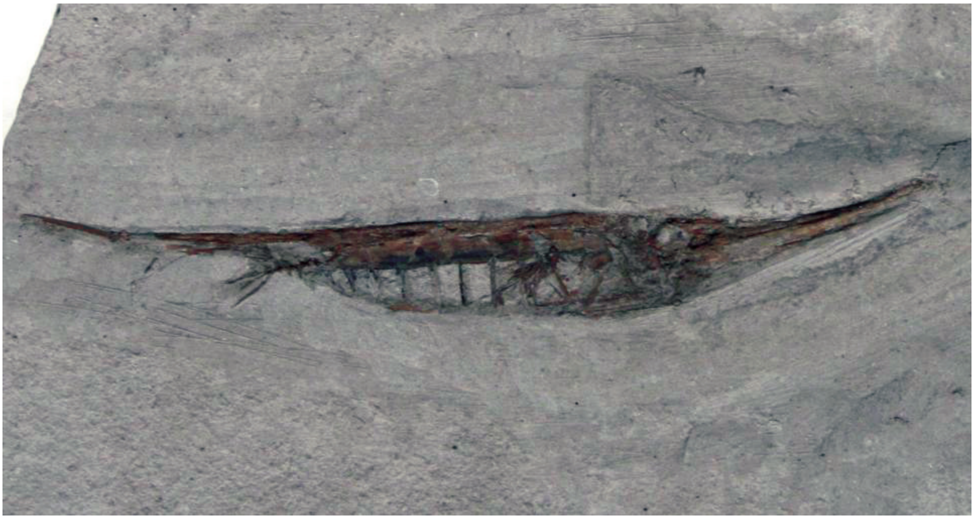

Figure 2. *Centriscus* sp. from the Neogene of Italy.

Indian Ocean species to make their way into the Mediterranean before the closure of the Isthmus of Suez is a question which will probably remain unresolved.

The mid-Pliocene optimum and the Gelasian crisis

The Mediterranean opened to the Atlantic Ocean but maintained its core tropical fauna, with many species, especially echinoderms and fishes, being documented survivors of the Messinian crisis. *Heterostegina*, though, did not survive into the Pliocene and the exact end of the last *Porites* reefs is uncertain.

The first two phases of the Pliocene, the Zanclian and the Piacenzian were warm. The so called Pliocene Optimum, between 3.60 and 2.58 million years ago was especially warm, Haywood et al. (2000) calculated a temperature 5 °C warmer and 400 to 1000 mm more precipitations at middle and high latitudes in Europe.

They consider that the Pliocene Optimum is a model for what is being called the present "Hyper Interglacial". High sea levels of +20 m to +35 m are also mentioned. Indeed the fossil fish fauna from the classical Piacenzian Marecchia site in Italy contains a list of the very earliest Lessepsian migrants of today: *Spratelloides*, *Stephanolepis*, *Sargocentron*, *Hemiramphus*, and *Etrumeus* (Sorbini 1988, Sorbini and Tyler 2001, Landini and Sorbini 2005). They entered the Mediterranean already in the 1920's and 1930's ahead of most of the subsequent migrants (Por 1978), as if waiting for the first opportunity to return.

Concrete data about the paleo-temperature in the Mediterranean is supplied by the presence of the symbiont-bearing foraminiferan *Amphistegina* in the Tyrrhenian Sea, but the absence there of *Porites* reefs (Checconi et al. 2007). The foraminiferan is limited by the winter isotherm 14 °C (Langer 2008), which is slightly higher than the 13.5 °C encountered there presently, but lower than the 15 °C which is the minimum for the hermatypic corals like *Porites* (Por 2008). *Amphistegina* resettled the Mediterranean recently (Hyams et al. 2002; Fig. 3), but although already widely spread, did not reach as yet the Tyrrhenian Sea.

The tropical sea urchin fauna, which survived the Messinian crisis, notably, different species of sand dollars (*Clypeaster*), cidaroids and *Diadema*, the needle-spined sea urchin, continued until the end of the Piacenzian. The Gastropoda of the Piacenzian Mediterranean were also typically tropical, with several species of auger shells (Terebridae), conus shells (Conidae), cowries (Cypreidae) and strombs (Strombidae). A sudden cooling started with the Arctic glaciation 2.58 million years ago. The third Pliocene phase, the Gelasian started the glacial cycles. It was the end of the tropical fauna of the Mediterranean.

Monegatti et al. (2002) use the complete disappearance of the augers as indicator for the start of the Gelasian. Cone shells and cowries were severely depleted and strombs disappeared altogether. Three species of cowry shells resettled the Mediterranean after 1980, coming from the Red Sea (Zenetos et al. 2004). The tropical sea urchin fauna suffered also a total depletion, but *Diadema*, re-colonized the Mediterranean after an interruption of more than two million years (Yokes and Galil 2006; Fig. 4).

The fishes from Marecchia also died out during the Gelasian, but used the Suez Canal to resettle the Mediterranean. Sorbini (1988) even considered that something similar to the Suez Canal connection of today might have made possible the influx of these Indo-pacific fish into the Pliocene Mediterranean.

The Pleistocene and the contact with the Tropical West Atlantic

During the low sea water temperatures of the Glacial periods, the Mediterranean was invaded by cold water biota from the northern Atlantic. Tropical biota live along the West African coast and the islands (Canaries, Madeira, Cap Verde), the so-called Senegalese fauna. They were, and still are to some extent separated from the Gibraltar portal, by the cold Canaries current. Furthermore, the west-east gradient of increasing temperatures within the Mediterranean, was steeper during the Glacial period than today. For instance, while in the Western Mediterranean, winter temperature fell as low as 7 °C, according to Thunell (1979), in the Levant basin the winter temperature was never lower than 16 °C. Today the gradient between west and east is only of 13 °C to 18 °C. The Levant basin functioned as a "cul de sac" of warm water, which was out of reach for the cold water species entering the Mediterranean.

During the last Interglacial, the Eemian Interglacial, dated between 125,000–110,000 years ago, with global temperatures 2 °C to 3 °C higher than today, there are fossil proofs that the West African tropical fauna succeeded to break the Canaries current barrier and the temperature barrier in the Mediterranean and reach the Levant. The whole episode lasted only for 14,000 years and was further subdivided into two warm pulses (van Kolf-

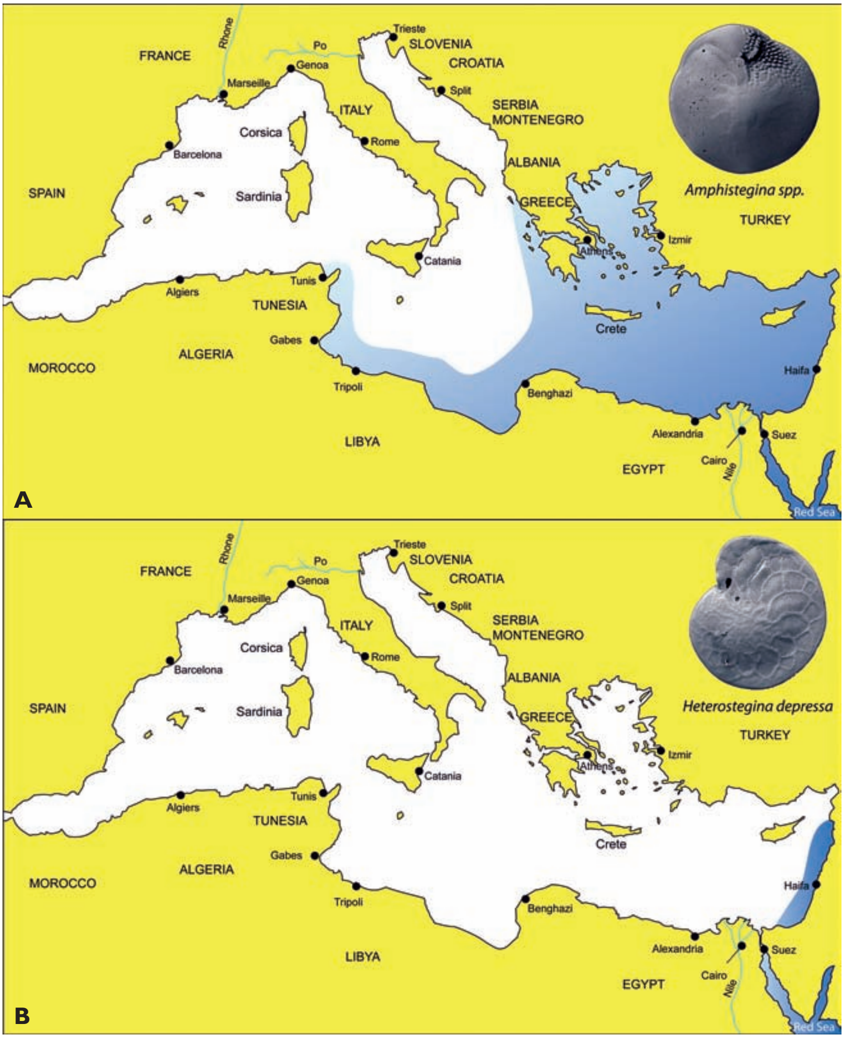

Figure 3. Distributional maps of the Lessepsian migrant Foraminifera (from Lange, 2008) **A** *Amphistegina* spp. **B** *Heterostegina depressa*.

schoten et al. 2003). It was characterized by a series of tropical Senegalese immigrant mollusk species such as *Strombus bubonius*, *Cardita senegalensis*, *Mytilus senegalensis*, and others.

It is interesting to comment that the Mediterranean, which lost its species of *Strombus* during the Gelasian crisis more than two million years ago, was episodically inhabited in the Eemian by the Senegalese *S. bubonius*, and recently received again two newcomer Indopacific Lessepsians, *S. mutabilis* and *S. persicus* (Zenetos et al. 2004).

Several species of fish with disjunct Levantine-Senegalese distribution, such as *Epinephelus haifensis* and *Sardinella madeirensis* are considered to be survivors of that Interglacial event, as well as a few invertebrates on record. It is evident that the high Interglacial sea level stands (sometimes +5 m are mentioned) were insufficient to sub-

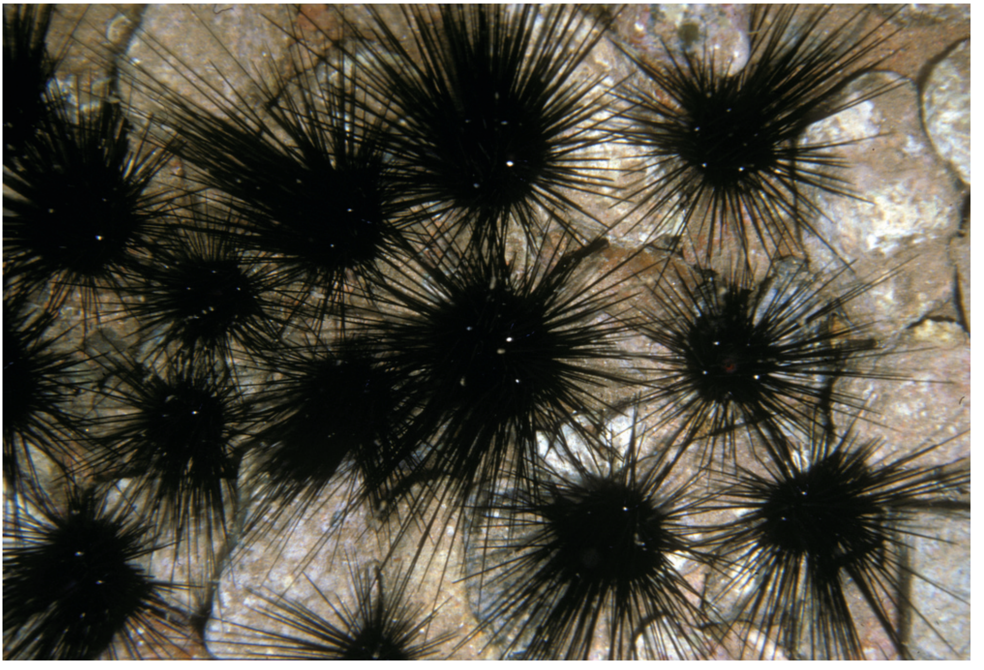

Figure 4. The sea urchin *Diadema setosum* an Indo-pacific newcomer in the Mediterranean.

merge the Isthmus of Suez. Therefore, the input of the Senegalese biota through the Gibraltar portal has been the only possible tropical input during the Pleistocene.

Even today, the analysis of the "neo-Atlantic colonizers" among the fishes (Ben Rais Lasram et al. 2008) indicates that since 1980 none of the species originated from a latitude exceeding 42.350 N and the last five species that arrived came even from a latitude south of 24.230 N (Ben Rais Lasram and Mouillot 2009.)

Congruence and equifinality allow re-colonization and enrichment

The Levantine Basin of the Eastern Mediterranean, entered the Climate Optimum, which started in the 19th century in the state of the warm-temperate to sub-tropical cul-de-sac situation, in which it has been all along the Pleistocene, since it was cut off from the eastern seas. Taviani (2002) called the Eastern Mediterranean a "Godot Sea" as if waiting to be colonized.

In the recent decades, the global increase in temperature is very marked and also expressed in the sea surface temperature of the Mediterranean (Fig. 5). As the sea surface temperatures increased, the man-made contact through the Suez Canal, opened in 1869, started to give access to hundreds of Indo-pacific species to the Mediterranean. The canal could not have functioned that way, if it would have been built 100 or 200 years earlier, during the Little Ice Age.

The congruence of these two events, the warming of the sea and the influx of the Indo-pacific biota, led to the present partial re-establishment of the Tethyan biota in the Mediterranean (Por 1990).

The extent of the anthropogenic factor in producing this global temperature increase is, as well known, a major issue of the public domain. However, as the results are concerned, both the natural and the human factors are equifinal, i.e. leading to similar results, although caused by different factors.

The principle of equifinality, fairly much used in geomorphology concerns also the much controversial subject of the nature of the Suez Canal connection. It is clearly anthropogenic, but it duplicates a natural seaway. Enlarged recently to 300 m in width, it is not much narrower than the Dardanelles in their narrowest part. The canal serves as a gateway for natural migration but facilitates also the expansion of ship-borne fouling biota. There are probably thousands of species that settled in the Mediterranean coming from the Red Sea and it is of no importance if they did it stepwise as “Lessepsian migrants” (Por 1978), or as one-jump noxious “Erythrean aliens” (Galil 2006). A warming Mediterranean is becoming more receptive also to species arriving accidentally with ship ballast and other artificial ways, adding to the number of successful establishment cases. The equifinal result is the same: it is a unique phenomenon of the establishment of a biogeographic province under our eyes. The last centuries of the Miocene Mediterranean with the Indian Ocean through the drying-out Mesopotamian trough must have been much more problematic and restrictive than the present so-called renewed “artificial” contact through the Suez Canal. Certainly, the 30 newly established tropical benthic foraminiferans (Hyams et al. 2002) will define a new Mediterranean geological phase for the future paleoecologists.

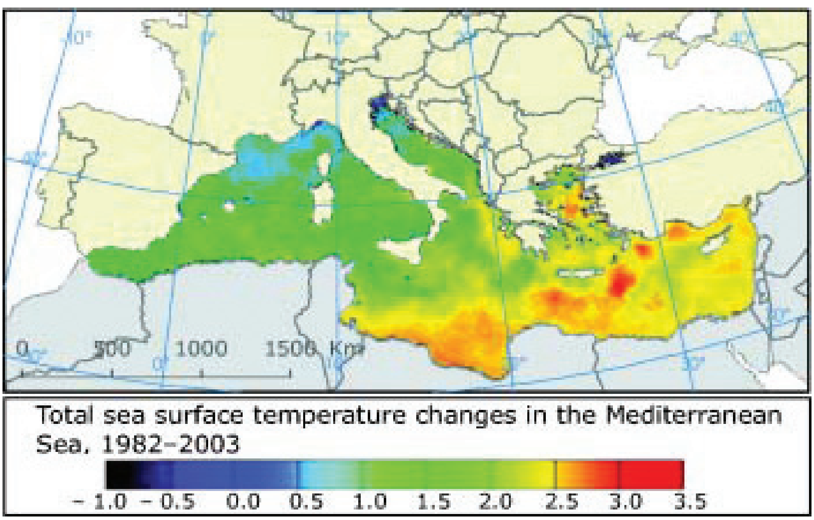

Figure 5. The rapidly expanding Lessepsian migrant cornet fish *Fistularia commersonii*.

Understandably, the issue of the alien invading species is a very worrisome one everywhere. Strangely so, not in the Mediterranean; unlike other marine water bodies, the Mediterranean, with the exception of the northern Adriatic, has been spared from the aggressive rogue invaders which wrought havoc elsewhere .This despite the famous case of *Caulerpa taxifolia* the horror-film "killer-alga"! The wide variety of probably thousands of species the newly settled Indopacific biota cannot be forced into the mold of aggressive invaders in order to conform to scientific fashion.

It seems hat explosive blooms of an invader as common in invasive events, cannot easily occur in oligotrophic seas like the Mediterranean or the Red Sea (see discussion in Por and Dimentman 2006). The northern Adriatic, in this sense, with its several cases of established invaders, is a eutrophic exception. Likewise, there is no proof that any of the newcomers reached functions that deserve the title of "worst invasive species" (Zenetos et al. 2005). None of the new settlers has led to the much feared prejudice or even extinction of a local Mediterranean species despite the still prevalent suspicion (Galil 2009), although the influx of new species is going on for well over half a century. Quite on the contrary, the Mediterranean biodiversity is much enriched.

Also none of the newly arrived species has since disappeared. The new colonizers are gradually enlarging their area, most probably as a function of the gradual warming of the sea. The first species of fish and mollusks have already crossed the straits of Sicily and entered western Mediterranean. The pipe fish *Fistularia commersonii* (Fig. 6) an absentee since the Messinian (see above), is one of the latest Lessepsian migrants and has in two years since its first appearance in the sea reached the western Mediterranean and practically re-occupied its original area (Golani 2000, Ligas et al. 2007). It seems that the process of re-colonization is gaining speed and amplitude.

The Tethyan species and their descendants are returning to their old haunts in the Mediterranean. To call them aliens is an anthropomorphic view, considering our historical times as the normal ones. The present Climatic Optimum represents a return to the Pliocene Climatic Optimum and thus, can be seen as a repetition, a cyclic event and not as an artificial disruption. For the squirrelfish *Sargocentrum rubrum* (Fig. 7) for instance, which inhabited the Mediterranean already five million years ago, we the humans, would be the alien invaders.

The newly active Gibraltar Portal

While attention is concentrated almost entirely on the Indo-pacific Lessepsian migrants, there is also an increasing settlement by tropical Atlantic newcomers entering the Mediterranean through the Straits of Gibraltar. Ben Rais Lasram and Mouillot (2009) consider that the currently warmer Mediterranean is acting increasingly as a "catchment basin" for southern species. Indeed of the 127 thermophilic species of fish which according to these authors supplemented the Mediterranean fauna, 65 fish are Lessepsians and 62 are Atlantic newcomers.

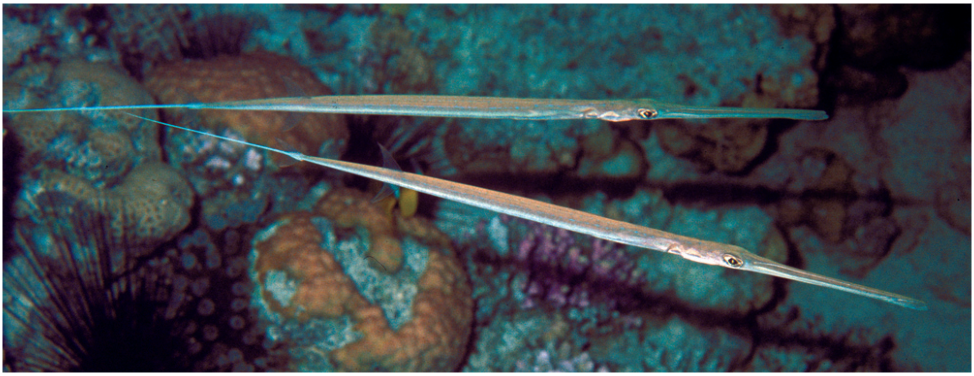

Figure 6. The quick migrant cornet fish *Fistularia commersonii*.

This two-pronged re-colonization of the Mediterranean is of course very evident in the mobile fish fauna and much less visible in the other biota. Yet there are cases already, for instance among the decapod crustaceans, such as of the stepwise advance of the boxer crab *Cryptosoma cristatum* (Galil et al. 2002)

Even with a warming western Mediterranean, the role of the Senegalese or the "Neo-Atlantic" colonizers will remain secondary to the Indopacific Lessepsian ones. First of all, the Senegalese province is not a typical tropical one, with coral species restricted to the two-dimensional reef-pavement stage, i.e. not building tri-dimensional reef structures. The reason for this is that the temperature of the coldest month can fall and has fallen in recent years below 18 °C, not allowing the buildup of reef structures. Besides, the interposed coasts of Mauritania and Morocco are influenced by the cold Canaries current and a strong upwelling and low winter temperatures. Only a radical change in the regime of the NAO (North Atlantic Oscillation) pattern will eventually allow easier access of tropical species to the Gibraltar portal.

The tropical enrichment of the Mediterranean

The influx of thousands of tropical species into the Mediterranean is without doubt the most remarkable biogeographic phenomenon of today. Even though its cause is closely related to the present climate change, there has not yet been any targeted national or international research effort to study this phenomenon. If something, even of a very much smaller scale, would be happening in the terrestrial domain, monitoring programs and computers would be churning, ecologists would be busy in the field and molecular biologists would analyze expatriate populations. We are mainly depending on decades on fishermen's data, on divers' observations and on information from shell collectors and beach combers. Even so, the number of reported newcomer species is around 1000, with a new report appearing at a weekly rate. The relatively few specialized studies of different taxa are of local faunas and not regional reviews. Considering that important and species-rich taxa like Porifera, Hydrozoa, Platyhelminthes, Nema-

Figure 7. The red squirrelfish *Sargocentrum rubrum* successful migrant since the 1930's (photo M. Fine).

toda, Acari, Harpacticoida, Ostracoda, Amphipoda, to name only a few of them, have not been studied, one can say that we know only the tip of the iceberg.

When the Levantine basin reached the lowest winter isotherm of 18 °C, which among others allowed the re-establishment of the symbiont-bearing foraminiferan *Heterostegina depressa* (see above; Fig. 3), it became in many aspects a tropical sea. This is indicated by an accelerated entry of tropical species, such as the gorgonarian *Acabaria erythraea* (Fine et al. 2004), the sea urchin *Diadema setosum* (Yokes and Galil 2006; Fig. 4), the upside-down jellyfish *Cassiopea andromeda* (Özgür and Öztürk 2008; Fig. 8), and the sea slug *Hypselodoris infucata* (Fig. 9). However, coral reefs, the typical formations of a tropical sea did not appear yet, although the conditions for their development already exist.

The scleractinian *Oculina patagonica*, the ivory coral, a species of uncertain, but probably Atlantic origin, has taken advantage of the warming sea and has explosively expanded around the southern Mediterranean during the last years, building coral pavements (see latest updates in Sartoretto et al. 2008).

The limits of the Tethyan return

The Mediterranean was the evolutionary centre of the Cretaceous and early Tertiary Tethys fauna. During the Miocene this centre shifted to the Indo-pacific as Mediterranean reefs became gradually depleted. The new Tethyan re-colonization of the Medi-

Figure 8 The Lessepsian migrant upside-down jellyfish *Cassiopea andromeda* in its natural benthic habitat (photo Matthias Schneider).

Figure 9. The newcomer Indo-pacific sea slug *Hypselodoris infucata* (photo Sven Kahlenbrock, courtesy Nathalie Yonow).

terranean is for the time being a limited one, though not a completely new phenomenon as expected by Bianchi (2007). In fact, the temperatures in the Levant basin are already more hospitable for a tropical coral sea than those in the Gulf of Suez.

The contact with the Red Sea is still limited by the conditions existing in the Suez Canal. At least the Levant Basin could already harbor thriving communities of Indo-pacific hermatypic corals, such as *Stylophora pistillata* or *Siderastrea savignyiana*. These species are resistant to temperatures as low as 13 °C in individual colonies and *Stylophora* forms reefs at minimum temperatures around 18 °C in the Gulf of Suez (Por 2008 and unpublished). The present constraints are that in the Suez Canal and mainly in the Bitter Lakes along the canal, winter temperatures are often below 15 °C, the substrate is soft and unsuitable for corals and turbidity is very high because of the passing ships. Corals have also short-lived larvae which cannot pass the more than 160 km long canal at once. They are also not able to live as ship-fouling or in ship ballast. Therefore, for corals, or for the Mediterranean to become a coral sea, the Suez Canal is still a barrier.

Together with the corals, a whole diversity of coral haunting fish, mollusks, echinoderms and other animals did not appear yet in the Mediterranean. For instance, the razor fish *Centriscus*, the Messinian survivor, extinct during the Gelasian (see above), which lives a in vertical position among coral branches and sea urchin spines, did not yet return to the Mediterranean. However, like *Fistularia*, the pipe fish, many species that have been retained by certain environmental constraints of the canal, will expand exponentially in the newly hospitable Mediterranean, once the barrier is broken.

It is probably only a matter of time till by natural or accidental means the first reef builders will emerge in the Levant Sea. Then, this sea, and together with it the whole Mediterranean will move another step closer to resemble the old coral sea of Tethys. This, of course, will only happen, if the current Climate Optimum will continue. If this trend of the tropical biodiversity enrichment of the Mediterranean is welcome and beneficial or not, belongs to the subjective domain and should not diminish by a iota the importance of and the scientific interest in this grandiose phenomenon.

References

Aguirre J, Perez-Munoz AB, Sanchez-Almazo I (2006). Benthic foraminifera assemblages on the lower Pliocene deposits of the Almeria-Nijar Basin (SE Spain). Revista espanola de micropaleontologia 38(2–3): 411–428

Ben Rais Lasram F, Tomasin JA, Guilhaumon F, Romdhane DD, Do Chi T, Mouillot D (2008) Historical colonization of the Mediterranean by Atlantic fishes: do biological traits matter? Hydrobiologia 607: 51–62.

Ben Rais Lasram F, Mouillot D (2009) Increasing southern invasion enhances congruence between endemic and exotic Mediterranean fish fauna. Biological Invasions 11(3): 697–711.

Bianchi CN (2007) Biodiversity issues for the forthcoming tropical Mediterranean Sea. Hydrobiologia 580: 7–21.

Checconi A, Bassi D, Passeri L, Rettori R (2007) Coralline red algal assemblage from the Middle Pliocene shallow-water assemblage at Monte Cetona (Northern Apennines, Italy). Facies 53 (1): 57–66.

Esteban M (1979/1980) Significance of the Upper Miocene coral reefs of the Western Mediterranean. Palaeogeography, Palaeoclimatology, Palaeoecology 29: 169–188.

Fine M, Aluma Y, Meroz-Fine E, Abelson A, LoyaY (2004) Acabaria erythraea (Octocorallia: Gorgonacea) successful invader to the Mediterranean Sea? Coral Reefs 24 (1): 161–164.

Galil BS (2006) The marine caravan: the Suez Canal and the Erythrean invasion. In Golasch S, Galil BS, Cohen AN (Eds) Bridging divides: maritime canals as invasion corridors. New York: Springer, 207–300.

Galil BS (2009) Taking stock: inventory of alien species in the Mediterranean sea. Biological Invasions 11: 359–372.

Galil BS, Froglia C, Noel P (2002) Crustacea Decapoda and Stomatopoda. In Briand F (ed.) CIESM Atlas of Exotic Species in the Mediterranean vol. 2.

Golani D (2000) First record of the bluespotted cornetfish from the Mediterranean Sea. Journal of Fish Biology 56: 1545–1547.

Golani D, Orsi Rellini L, Massuti F, Quignard JP (2002) Fishes. In: Briand F (Ed) CIESM Atlas of Exotic Species in the Mediterranean. Vol. 1. Fishes. CIESM Publishers, Monaco, 1–256.

Griffin DL (2002) Aridity and humidity: two aspects of the late Miocene climate of North Africa and the Mediterranean. Palaeogeography, Palaeoclimatology, Palaeoecology 182: 65–91.

Haywood AM, Dellwood BW, Valdes PJ (2000) Regional warming: Pliocene (3 Ma) paleoclimate of Europe and the Mediterranean. Geology 28 (12): 1063–1066.

Harzhauser M, Kroh A, Mandi O, Piller WE, Goehlich U, Reuter M, Berning B (2007) Biogeographic responses to geodynamics: a key study all around the Oligo-Miocene Tethyan seaway. Zoologischer Anzeiger 246: 241–256.

Hyams O, Almogi-Labin A, Benjamini C (2002) Larger foraminifera of the SouthEastern Mediterranean shallow continental shelf off Israel. Israel Journal of Earth Sciences 51: 169–179.

Kolfschoten Th van, Gibbard PL, Knudsen KL (2003) The Eemian Interglacial: a global perspective: introduction. Global and Planetary Change 35: 147–149.

Landini W, Sorbini L (2005) Evolutionary dynamics in the fish faunas of the Mediterranean basin during the Plio-Pleistocene. Quaternary International 140–141: 64–89.

Langer MR (2008) Foraminifera from the Mediterranean and the Red Sea. In Por FD (ed.) Aqaba-Eilat, the improbable gulf: environment, biodiversity and preservation. Jerusalem: Magnes Press, 397–415

Ligas A, Sartor P, Sbrana M, Sirna R, De Ranieri S (2007) New findings of *Fistularia commersonii* Rüppell, 1835 and *Sphoeroides pachygaster* (Müller & Troschel, 1848) in the northern Tyrrhenian Sea. Atti Soc. Toscana Sci. Nat. Mem. Serie B, 114: 131–133.

Monegatti P, Canali G, Bertoldi R, Albinelli A (2002) The classical Piacenzian Monte Falcone-Rio Crevalese section (Northern Italy): palynological evidence and biomagnetostratigraphic constraints for climatic cyclicity and local mollusk extinctions. Geobios 35: 219–223.

Néraudeau D, Goubert E, Lacour D, Rouchy JM (2001) Changing biodiversity of Mediterranean irregular echinoids from the Messinian to the Present Day. Palaeogeography, Palaeoclimatology, Palaeoecology 175 (1–4): 43–60.

Özgür E, Öztürk B (2008) A population of the alien jellyfish, *Cassiopea andromeda* (Forrskål, 1775) [Cnidara: Scyphozoa: Rhizostomea] in the Ölüdeniz Lagoon, Turkey. Aquatic Invasions 3 (4): 423–428.

Por FD (1978) Lessepsian migration. The influx of the Red Sea biota into the Mediterranean by way of the Suez Canal. Ecological Studies 23. Berlin: Springer Verlag.

Por FD (1990) Lessepsian migration. An appraisal and new data. In Godeaux J (ed.) A propos des migrations lessepsiénnes. Bulletin de l'Institut Océanographique Monaco. Numéro spécial 7: 1–10.

Por FD (2008) Life beyond 41 ppm. Metahaline environments and anchialine pools in the Gulf of Aqaba-Eilat. In Por FD (Ed) Aqaba-Eilat, the improbable Gulf: environment, biodiversity and protection. Jerusalem: Magnes Press, 125–152.

Por FD, Dimentman Ch (2006) Mare Nostrum. Neogene and anthropic history of the Mediterranean with emphasis on the Levant. Sofia-Moscow: Pensoft. 349 pp.

Sartoretto S, Harmelin J-G, Bachet F, Bejaoui N, Zibrovius H (2008) The alien coral Oculina patagonica De Angelis 1908 (Cnidaria; Scleractinia) in Algeria and Tunisia. Aquatic Invasions 3 (2): 173–180

Sorbini L (1988) Biogeography and climatology of Pliocene and Messinian fossil fish from Eastern Central Italy. Bollettino del Museo di Storia Naturale di Venezia 14: 1–85.

Sorbini L.,Tirapelle-Rancan S.,1980. Messinian fossil fish of the Mediterranean. Palaeogeogra phy,Palaeoclimatology,Palaeoecology 29:143–154

Sorbini L, Tyler JC (2001) Review of the fossil filefish of the family Monacanthidae (Tetraodontiformes) from the Pliocene of Italy. VI European Workshop on Vertebrate Paleontology, Florence and Montevarchi, September 19–21 2001. Abstract volume. p 56.

Stampfli GM, Borel GD (2004) The TRANSMED transects in space and time: Constraints on the paleotectonic evolution of the Mediterranean Domain. In: Cavazza W, Roure F, Spakman W, Stampfli GM, Ziegler P (Eds) The TRANSMED Atlas: the Mediterranean Region from Crust to Mantle. Springer Publishers, 53–80.

Taviani M. (2002) The Mediterranean benthos from late Miocene up to present: ten million years of dramatic climatic and geologic vicissitudes. Biologia marina mediterranea 9: 445–463.

Thunell RC (1979) Climatic evolution of the Mediterranean Sea during the last 5.0 million years. Sedimentary Geology 23: 67–79

Yokes B, Galil BS (2006) The first record of the needle-spined urchin *Diadema setosum* (Leske, 1778) (Echinodermata: Echinoidea: Diadematidae) from the Mediterranean. Aquatic Invasions 1 (3): 188–190.

Zenetos A, Gofas S, Russo G, Templado J (2004) Mollusks. In Briand F (ed.) CIESM Atlas of exotic species in the Mediterranean vol. 3 Monaco (updated website, May 2008)

Zenetos A, Cinar ME, Pancucci-Papaodopoulou MA, Harmelin JG, Furnari G, Andaloro F, Bellou N, Streftaris N, Zibrowius H (2005) Annotated list of marine alien species in the Mediterranean with record of the worst invasive species. Mediterranean Marine Science 6/2: 63–118.

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REVIEW ARTICLE

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The biodiversity network BioFrankfurt: An innovative strategic approach to integrative research, conservation, and education

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Abstract

Responding to inadequate awareness of the outstanding importance of biodiversity, the BioFrankfurt network was founded in 2004 in the State of Hesse, Germany. It is presented here as a case study and may serve as a model for other parts of the world, such as the Middle East. In 2007, only about 26% of the German population were familiar with the term "Biodiversity", and most of them only had a vague idea about its meaning. The BioFrankfurt network of institutions addressed this problem, raising public awareness and supporting research, education and conservation. A regional biodiversity education program has been developed and delivered to more than 500 schools. Since 2007, an innovative public relations campaign combines raising awareness on regional biodiversity issues with activities to improve the public image of the Frankfurt area. Because of its geographical focus, the network's activities gained the attention of local and regional politicians and other decision makers, culminating in the joint establishment of a new Biodiversity and Climate Research Centre by BioFrankfurt member institutions. The success of current activities attracts interesting partners, resulting in challenging cooperation initiatives. The authors are convinced that the network's concepts and activities have a great potential to profoundly enhance the notion and acceptance of biodiversity issues elsewhere.

Keywords

BioFrankfurt, biodiversity network, education, public awareness, scientific communication

Introduction

Biodiversity is the natural wealth of the Earth, and provides the basis for human life and prosperity (Wilson 1988, Gaston and Spicer 2005). With the launching of the Convention on Biological Diversity (CBD) at the United Nations Conference on Environment and Development (UNCED) in 1992, the maintenance of biodiversity became a global priority. Biodiversity provides ecosystem services, such as access to clean drinking water, clean air, timber, balancing climate, protection from natural hazards, erosion control, pollination, disease and biological pest control, and pharmaceutical substances. It also provides numerous non-material benefits of recreational, cultural, spiritual, aesthetical and intellectual value. Yet, the majority of people, probably in most parts of the world, are unaware of the fundamental significance of biodiversity for their life, and for past, current, and future cultures and economies. In response to this lack of awareness, we founded a biodiversity network, which is presented here as a case study. It may serve as a model for other parts of the world, such as the Middle East.

Biodiversity – a complex issue

In 2007, a representative survey of 2000 persons from all parts of Germany was conducted, covering all major population subgroups (i.e. various ages, income levels, professions, and urban vs. rural areas). When asked the question: "Have you ever heard or read the term biodiversity (or biological diversity)?" only 25.7% replied with "yes", while 74.3% replied with "no" ("I do not know" was not offered as an option). Only few of the respondents replying with "yes" knew the proper meaning of the term biodiversity.

In a second step, we asked in more detail what respondents associate with the term "biodiversity" by choosing one out of four possible replies. Here below is the percentage of respondents replying with "yes" to one of the options:

"Does biodiversity refer primarily to a variety of healthy food?"	29.6%
"Does biodiversity refer to a human disease?"	2.4%
"Does biodiversity refer to the diversity of genes, species, and ecosystems?"	52.6%
"Does biodiversity refer to a modern biotechnology?"	15.4%

More than half of the respondents associated "biodiversity" correctly with what it commonly stands for in the conservation sciences. The number of correct replies was significantly higher among persons with high school or university education (70.3%) than in other groups. Persons with the lowest level of education showed a significantly increased tendency to associate biodiversity with healthy food. Inhabitants of larger cities (> 100,000) were significantly more likely to reply correctly, which might reflect a generally higher level of education in cities as compared to the countryside.

When we asked the question „Do you think that threats to biological diversity pose serious problems to mankind, similar to those associated with climate change?" 48.2%

responded with "yes", 15.4% with "no", while 36.4% were undecided. Again, persons with higher education were significantly more likely to reply positively. The results underline that the extent to which agriculture, medicine, and industy rely on natural resources and free ecosystem services is still widely ignored.

BioFrankfurt – A unique Biodiversity Network initiative

The Frankfurt area in Germany has a considerable number of institutions and organisations with international expertise in a wide range of biodiversity issues. Fifteen of them are members of BioFrankfurt. The BioFrankfurt network of institutions was founded in 2004 in order to address a common concern for biodiversity. It aims at stimulating interaction in four areas, in which individual institutions make available their extensive experience: (i) biodiversity research, (ii) conservation management, (iii) sustainable development, and (iv) education. In the networking process, experts in these fields pool their knowledge and experience in order to strengthen public awareness of the significance of biodiversity, and to develop improved conservation strategies. In spring 2007, a local office was established to co-ordinate all network activities, support members in developing and executing joint projects, and to serve as a central contact point.

BioFrankfurt's strategic approach

A generally intelligible approach, combined with examples of the role that biodiversity plays in people's everyday life is needed to arouse public interest in biodiversity. Therefore we use a simplified definition of biodiversity, based on the one given in the Convention on Biological Diversity, which describes biodiversity as "...the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (United Nations 1993). We additionally explain that there is much more diversity in biological systems, e.g. functional diversity within the ecosystem, and that today's biodiversity is the result of past and presently on-going evolutionary processes. Recent results of medical, technical, or biological research, conservation and sustainable development initiatives serve as examples, illustrating the close interaction between (global) biodiversity and human welfare.

Based on this concept, an educational program focussing on biodiversity has been developed to raise public awareness. One example is the selection of annual themes to which members in the network contribute. For example, in the "Darwin Year 2009" numerous events, talks, excursions, guided tours, and symposia were organised to explain the evolutionary processes that resulted in the present-day biodiversity. Additionally, in the month of May, a region-wide annual "Biodiversity Week" sets its main focus on outdoor activities for families.

Schools and teachers are addressed with a targeted information and training program. This includes workshops, guided tours and special teaching aids on different aspects of biodiversity to foster the integration of biodiversity issues into curricula. To ensure long-term availability of the program, the guided tours for schools on selected topics of biodiversity education were integrated into the regular educational programs of four network partners. Themes include specific exhibits (Museum of Nature, Zoo, Botanical Garden), characteristics of regional biodiversity (outdoor events in a local forest), and refer to school curricula. The tours are promoted on the BioFrankfurt website and in a brochure.

An innovative public relations campaign was initiated by one of our members. It combines information on regional biodiversity with image improving initiatives for the Frankfurt area. Scientific results on regional biodiversity are presented on eye-catching posters throughout the city, combined with films, press articles, talks, guided tours, and other activities. The surprising biological diversity of the urban area is considered a valuable contribution to everyone's quality of life. Additionally, comparisons with other regions of the world – closely connected with Frankfurt through its international airport – are used to raise attention to global biodiversity.

These activities also gained the attention of politicians from the city of Frankfurt up to the Government of the Federal State of Hesse. One of the most prominent outcomes at the policy level was the joint establishment of a new Biodiversity and Climate Research Centre (BiK-F) by the Senckenberg Research Institute and Museum of Nature, and the Goethe University of Frankfurt, both members of BioFrankfurt. The mission of this new Centre of Excellence is to carry out research on the interactions of biodiversity and climate at highest international levels, using state-of-the-art methods ranging from satellite-based remote sensing to advanced genomics and mass spectrometry. Scientists of the centre document and analyze past and present biodiversity patterns and processes, providing reliable predictions of future developments. The Centre integrates expertise in the investigation and management of climate-related biodiversity changes.

Conclusions

BioFrankfurt succeeded in fostering awareness of biodiversity-related issues and their implications on human quality of life. Supported by continuous fundraising, a targeted educational program on biodiversity is now available to over 500 schools. Within four years, BioFrankfurt gained wide recognition by politicians and other decision makers. It is also considered an important project partner for Non-governmental Organisations (NGOs) and the private sector. Science and research profit substantially from the network's activities. In addition, the continuous exchange of information and ideas among network partners helps to better understand each other's goals and positions, and promotes the target-oriented design of future projects.

We have no doubt that similar networks in other parts of the world can build on the experience of BioFrankfurt. Given the long tradition of scientific and cultural exchange among institutions in Frankfurt and their counterparts in the Middle East, the potential of building up synergies that strengthen biodiversity research and conservation is particularly promising. Local conditions and resources will largely determine how and to which extent the idea can be implemented elsewhere but we are convinced that the basic concept is suitable to be transferred and work successfully under a wide range of social, cultural, economic or political conditions. Even a moderate financial base will help initiating co-operations. We further encourage the establishment of super-networks, linking up biodiversity networks in various parts of the world.

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References

Gaston KJ, Spicer JI (2005) Biodiversity: An Introduction. 2nd ed., Blackwell.

United Nations (1993) Convention on Biological Diversity. United Nations Treaty Series, vol. 1760, Article 2.

Wilson EO (1988) Biodiversity. National Academy Press, Washington D.C.

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REVIEW ARTICLE

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Urbanisation in the United Arab Emirates: The challenges for ecological mitigation in a rapidly developing country

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Abstract

The United Arab Emirates is a small Gulf country with perhaps the fastest rate of infrastructure development anywhere. While there is legislation in place requiring environmental impact assessments (EIA) to be undertaken for all major projects, the speed and scope of development provides special challenges in devising and implementing ecological mitigation against the loss of habitats and biodiversity that this development engenders. This paper critically discusses mitigation strategies that have been attempted, and suggests mitigation strategies in the local context. It is hoped that this will assist both the environmental consultants involved in the EIA process and the competent authorities who issue development licences, to the benefit of the remaining native biodiversity of the area.

Keywords

United Arab Emirates, UAE, mitigation, environmental impact assessment, biodiversity, conservation, translocation

Introduction

The United Arab Emirates (UAE) is a relatively small country (83,600 km^2) with coastline on both the Gulf of Oman and the Arabian Gulf. Politically, the UAE are a federation of seven individual emirates, each with a considerable degree of autonomy. The land is predominantly arid, much of it is classified as hyperarid (Böer 1997), with a harsh climate of high temperatures, low and irregular precipitation and consequent high evapotranspirative stress. Nonetheless, it is a country of contrastring landscapes, with a wide range of habitats including mountains, sand and gravel deserts, sabkhas (salt flats), and mangrove forests. The diverse fauna and flora exhibit a fascinating range of adaptations to survive in this harsh and forbidding landscape.

Until the discovery and exploitation of oil and gas in the mid-20th century, the human population of the UAE was small and the impact of the human economy on the natural environment was very limited. Since then, the influx of huge wealth, and the economic development that this has allowed, has drastically altered this situation. The human population has risen exponentially from an estimated 86,000 in 1961 (Environment Agency Abu Dhabi), and is expected to top five million during 2009. One consequence of this has been the extremely rapid emplacement of a modern infrastructure, including an extensive highway and road network, residential areas, shopping malls, golf courses, airports and industrial facilities. The scale of such ambitious developments (often referred to as 'mega-projects') has been staggering and superlative on a world scale. Dubai now claims the world's tallest building, largest shopping mall, longest indoor ski slope and largest artificial island. Further projects are planned or already under construction, including the largest airport, artificial canal and seafront developments, although some parts of these developments are currently on hold as a result of the global economic crisis. Abu Dhabi city is also currently expanding at an explosive rate with major developments on the mainland and the adjacent Sadiyat, Reem and Yas Islands.

Conspicuous consumption has also placed the UAE in the unenviable position of having the world's highest ecological footprint at 9.5 global hectares per capita, highest per capita carbon footprint (Global footprint network 2008) and one of the highest per capita water consumption rates. From a plethora of possible examples in different emirates, we briefly describe two projects from Dubai.

The Dubai World Central (DWC) development at Jebel Ali combines the Al Maktoum International Airport with a range of mixed residential, commercial, logistics and recreational facilities. When development is complete the site is planned to house 900,000 people and become the world's largest air passenger and cargo hub. Before development started in 2006, the 140 km^2 site was an area of sand sheets, low dunes and saline plains used principally for low density livestock grazing. The area had a relatively rich desert fauna and flora, including at least nine species of mammals, diverse resident and visiting bird species, 17 reptile species, a wide range of invertebrates, and 43 species of plants (Gardner and Aspinall 2006). While ecological data, life histories and population status are poorly known for numerous species, it is strongly suspected that many species are declining. Species recognized to be of national conservation concern on the site included free-ranging mountain gazelle (*Gazella gazella cora*), cream-coloured courser (*Cursor cursorius*), Pharaoh eagle owl (*Bubo ascalaphus*), the Persian wonder gecko (*Teratoscincus keyserlingii*), Leptien's spiny-tailed lizards (*Uromastyx aegyptia leptieni*) and the ghaf tree (*Prosopis cineraria*).

A second example is the 75 km long Arabian Canal project that is being excavated around Dubai World Central. This canal and landscaping project is being undertaken for real estate purposes, rather than transportation or irrigation. According to the developers (Limitless, Dubai), this project will eventually develop 100 km^2 of land, house up to 2.5 million people, involve moving one billion cubic metres of sand and rock, and build hills up to 200 m tall. The excavation of the canal itself is estimated to cost $ 11 billion, and the development of the "city" will cost a further $ 50 billion. Prior to development starting in 2007, the area was of great interest in terms of its rich biological and habitat diversity. It also had high landscape value which gave a feeling of true wilderness, despite being so close to the major urban and industrial areas of Dubai and Jebel Ali (Gardner and Howarth 2007). As a result of the global economic crisis, it was announced by the developers in late 2008 that the second phase of the development, primarily concerned with inland areas, had been placed on hold, and the proposed schedule for resumption is currently (July 2009) not known.

With infrastructure developments on this scale, the consequent pressures on the natural environment have been drastic, both within the project areas and outside. For example, the enormous demand for aggregate, stone and cement have led to very extensive quarrying in the mountains and gravel extraction on the outwash plains, resulting in loss of pristine mountain habitat and extensive dust pollution. The development of artificial islands, ports, marinas and coastal residential areas has brought alteration and degradation of marine habitats through pollution and dredging.

The UAE, recognizing the need to protect the environment, has emplaced a considerable body of legislation at both federal and individual emirate levels. The federal environmental law of 1999 (No. 24) addresses the protection of the environment and development of its natural resources. As is laid out in Article 2, implementation aims to achieve conservation of natural resources and biological diversity. Furthermore, Article 3 requires developers to identify parts of projects that will cause harm to the environment and identify areas of special environmental importance or sensitivity. Article 4 specifically requires any developer to undertake an environmental impact assessment (EIA) for any development project, including a baseline ecology survey.

Although EIAs are now being undertaken for most categories of development projects in compliance with the law, their remits cover individual project sites with little or no integration into the overall ecology of the landscape or species ranges. It is unfortunately also true that ecology surveys and planning have often been undertaken after construction decisions have been made, and in some cases, after clearing and levelling of the land has started. Moreover, the present limited scientific understanding of habitat ecology and lack of effectively tested mitigation measures, together with limited implementation of suggested mitigation, weakens the EIA process.

The UAE prides itself on the rapid pace of development, in which projects may go from the drawing board to completion in times unheard of elsewhere. Hence in many projects, the contracting companies do not have adequate time to complete the usual requirements of ecological survey for EIA, and nor, in many cases, do master developers or government authorities, insist that they try to do so. Instead, the methodologies of rapid assessments are used, often with a single snapshot survey undertaken over a few days and without any assessment of seasonality. This may result in a highly distorted view of the ecosystem concerned. For example, in a climate regime where rainfall is unpredictable, the annual and ephemeral flora may only be present for a few weeks, and in drought years, may not appear at all. Surveys conducted in mid-winter may grossly underestimate reptile abundance and diversity, and of course passage migrant birds may only be present for days or weeks. Nonetheless, such transient fauna and flora are key parts of the local ecosystem. Experienced ecologists with local knowledge may be able to factor in such species during a rapid assessment survey, but many assessments are made by visiting ecologists without an adequate background. Indeed many of the ecological baseline surveys being undertaken are woefully inadequate 'walkover surveys' without any consideration of the nocturnal fauna or more cryptic species such as the bats, geckoes, arthropods and other invertebrates, despite these being key parts of local ecological interactions.

The aim of this paper is to discuss possible mitigation options that have been proposed and, in some cases, implemented, in the hope that such suggestions and discussion may assist the EIA planning process in the UAE and other countries.

Mitigation Strategies

Fauna and flora translocation

Destruction and displacement of flora and fauna during development is a major cause of biodiversity loss and habitat fragmentation. One mitigation option that has been proposed and implemented is the translocation of animal and plant species from the development sites to new 'safe' locations. Indeed Dubai Municipality, the competent authority in Dubai Emirate, maintains a list of species they require to be collected and translocated (Dubai Municipality Environment Department no date), and similar exercises have been attempted in Abu Dhabi. Typical species translocated are gazelle (*Gazella* spp.), cape hares (*Lepus capensis*), spiny-tailed lizards and ghaf trees, and in the marine environment, corals. Animal translocations have been hailed in the popular press as 'rescuing' or 'saving' the animals (e.g. Gulf News, 25 June 2005).

Attractive as this option may appear, translocation should generally be viewed as a controversial method of last resort. Translocation is a highly specialised, time consuming and expensive method, which, where possible, should be used in conjunction with other forms of mitigation. For success, operations of this kind require extensive planning and, in many circumstances, need several years or even decades to complete. The success rate may be low, especially as criteria for judging success are not always rigorous and unsuccessful attempts are less likely to be published. Translocations which aimed to solve human-animal conflicts have generally failed (Fischer and Lindenmayer 2000). Without adequate safeguards, translocations may actually result in increased environmental disturbance, and suffering and stress for the animals concerned. The IUCN/SSC Re-introduction Specialist Group (RSG) has produced stringent guidelines for effective translocation and reintroduction programmes (IUCN/SSC Re-introduction Specialist Group 1998). However these guidelines were never designed for the release of rescued animals from sites under development, but rather for the re-establishment of populations in areas where they have become locally extinct (re-introductions) or depleted (restocking). Nevertheless, the guidelines are useful as a management tool. In summary these require that translocation should only take place where:

- The habitat requirements of the species are satisfied and are likely to be sustained for the foreseeable future.
- The capacity of the area it is proposed to restock should be investigated to assess if the level of the population desired is sustainable.
- The animals or plants being used for restocking must be of the same race as those in the population into which they are released.
- The long term protection of the re-introduction area is assured.
- Actions are based on thorough research into previous re-introductions of the same or similar species.
- Adequate post release monitoring is planned.

Unfortunately, the necessary ecological and monitoring studies have yet to be conducted in the UAE, and translocations have been undertaken in an ad hoc manner. For example, the collection of Leptien's spiny-tailed lizards on sites scheduled for development, and their translocation to another site, where resident animals may already be at carrying capacity, is likely to result in increased competition for burrows, food and space. The likely outcome is stress and mortality for resident and translocated animals alike. Simply providing food and water in the release site, to maintain unnaturally high populations, is not a sustainable strategy, and the consequent effects of this on other species in the ecosystem are unknown. Moreover, if animals are released during the hotter parts of the year from April through to October, and they cannot immediately find shelter in a burrow, they may suffer heat stress and die. In a recent analysis of reptile and amphibian translocations attempted worldwide between 1991 and 2006, the success rate remained low. Of eight translocation attempts motivated by human wildlife conflict (such as development mitigation) only one was considered successful (Germano and Bishop 2009).

Hares have been routinely captured by chasing them down by vehicles. Survival after such trauma has not been monitored. Similarly, corals relocated using inappropriate techniques or placed in sub-optimal environments can have high mortality rates, defeating the purpose of the exercise. Mature ghaf trees grown under natural conditions develop a long tap root to reach the water table. Such roots in translocated trees will be severed, and these trees may therefore be reliant on artificial irrigation for many years. Indeed, it is not certain that trees drip irrigated from the surface can be induced to regrow a tap root.

It is vital that the objectives of any translocations are clear. It is recommended that translocations should only be attempted to re-introduce species into areas from which they have been extirpated through overexploitation or habitat degradation, or to restock to areas where they are similarly depleted. In doing so, the IUCN guidelines should be adhered to rigorously. In order for translocation to be used effectively as a mitigation method, there is an urgent need for detailed ecological and behavioural studies of the organisms concerned together with adequately funded, properly researched and monitored trial translocations. Otherwise such efforts are likely to be futile and divert resources from more effective mitigation strategies. The use of translocation, without full compliance with IUCN guidelines, in a misguided attempt at animal welfare, must be avoided.

Topsoil storage and land restoration

Mitigation of habitat loss may be achieved by land restoration, so that degraded areas can once again sustain habitats of conservation value (Vécrin and Muller 2003). While the difficulties of habitat and community translocation should not be minimised (Bullock 1998), the long-term value of habitat restoration for biodiversity conservation is apparent (Young 2000). A key resource for habitat restoration is the removal, storage and reuse of top soil from areas undergoing development.

The uppermost layer of sandy desert soils includes seeds which only germinate under suitable conditions. In desert areas, seeds may remain dormant for decades, but still germinate under the right conditions. The removal of this layer during development effectively destroys most of the seed bank, contributing to biodiversity loss. In many countries, an integral part of any development involves setting aside the turf and topsoil removed during earth works and then reusing it to reclaim land. For example, in emplacing pipelines, the corridor is stripped of turf and topsoil, the pipeline is trenched, and the turf and topsoil are used to resurface the corridor. After re-establishment, the disturbance is minimised. Not only does this ensure that biodiversity loss is reduced, but it encourages the use of the natural flora in landscaping. In desert areas, where the percentage of plant cover may be low for much of the year, the value of the topsoil may be overlooked, but is nevertheless critical to rapidly re-establish the ephemeral flora.

In order to effectively store and re-use the sandy soils in the UAE, the optimal stripping depth and storage conditions need to be established. It is widely recognised that soils can deteriorate if they are not stored under suitable conditions. For example compaction and consolidation during storage deteriorates soil structure (Hunter and Currie 1956). With increasing depth in soil stores, conditions of the soil change, sometimes rendering the soil anaerobic (Harris et al. 1989). This changes the soil's physical and chemical property and may render it less useful for reclamation procedures. Hence, a classification of top soil types and research into top soil re-use for mitigation of habitat loss should be a high priority, and funding such research would be one means of off-site mitigation.

In projects where the land surface will not be built on or 'greened', such as along pipeline corridors, under pylon lines or areas of levelled or remodelled surface, we suggest that replacement of topsoil for habitat restoration should be a required mitigation strategy.

Wildlife Corridors

Fragmentation of habitats is widely recognised as a major factor leading to biodiversity loss, in terms of habitats, species and genetic diversity. One possible mitigation measure to reduce such fragmentation of species ranges into isolated "islands" is the provision of corridors connecting them (Noss and Harris 1986). Such corridors can either function as valuable linear habitat for smaller species such as reptiles and invertebrates, or as dispersal corridors (Harris and Gallagher 1989) for larger animals. Corridors have at least five functions (Harris and Gallagher 1989): they allow wide-ranging animals to travel, migrate or meet mates; allow pollination and propagation of plants; allow genetic interchange between populations; allow populations to move in response to environmental changes; and allow individuals to re-colonize habitats in which they have become locally extinct.

Creating wildlife corridors in an arid environment is a major challenge due to the harsh climate, low population densities and highly adapted species assemblages. Regardless of the challenge, such corridors are needed to maintain biodiversity and provide suitable habitats for displaced species. For example, recent highway construction and large-scale quarrying activities in the UAE mountains are fragmenting the mountain ecosystem into ever smaller blocks. Provision of corridors linking these areas may allow endangered species such as the caracal lynx (*Felis caracal schmitzi*) and Arabian tahr (*Arabitragus jayakari*) to retain viable populations. As the mountain areas fall into several different emirates, this will require coordinated planning and implementation at the federal level.

Mitigation strategies here are particularly important for projects such as highways and pipelines, which cross the mountain range. Highways in the UAE are usually fenced and lit, and provide impassable obstacles to larger mammals. We recommend that developers be required to build bridged and unfenced wildlife underpasses (which could also function as wadi crossings). Pipelines also should be unfenced and buried, with areas of restored natural surface to allow free movement of animals.

On-site mitigation

On-site mitigation aims to minimise environmental impacts on natural biodiversity within the boundaries of the development site itself. A variety of mitigation strategies are possible, depending on the nature of the site and project.

Preservation of natural habitats

If possible, areas of the site should be set aside as natural habitat and be retained as far as possible in their native state. Even small areas may be sufficient to maintain plants, insects, lizards and small mammals and provide habitat for visiting birds. They may also be extremely valuable as areas for environmental education and recreation. Such areas should be fenced or clearly marked off so that they are not used by contractors as dumping or lay-down areas. Some management of sites may be appropriate, such as provision of signage, information panels, paths or walkways, birding hides, and management of grazing. Such areas can also be designed so that they interlink with other sites providing corridors.

In coastal areas mangroves and shorebird feeding grounds are threatened. They are home to a great variety of biota and are of particular importance for fish, bird and insect species. The shallow sea and intertidal mudflats are important feeding areas for the visiting shorebirds, passage migrants and residents. These should be protected from further damage by minimising future dredging, careful emplacement or removal of dredge spoils, avoidance of dumping construction and other materials onto them and vigilance against pollution.

Preservation of existing indigenous mature trees and shrubs.

Indigenous trees and shrubs are of particular ecological importance in the desert environment as they provide shade and shelter for native wildlife, such as gazelles, and habitat for native invertebrates. They also have an important cultural association and are aesthetically pleasing in the landscape. The factors affecting natural regeneration are poorly known, but overgrazing by goats and camels is likely to be preventing most regeneration. As they take many years to become established, it is important to maintain standing trees wherever possible, designing around them where necessary. In the desert environment ghaf and acacia (*Acacia tortilis* and *A. ehrenbergiana*) are the major trees. The shrub, *Leptadenia pyrotechnica* is a major structural part of the vegetation in some areas, and provides shelter for a variety of animal species such as Arabian hares. In mountainous and gravel plain areas a variety of trees occur, but sidr (*Ziziphus spina-christi*), growing to a large size in the wadi beds, are particularly important.

Sympathetic planting and maintenance

Sympathetic landscape and garden planting, using native species where possible, can make a large difference in the conservation value of a site. Moreover native species tend to have low water requirements, are often salt tolerant and resistant to disease. It is recommended that native trees, shrubs and grasses are used as much as possible in landscaping. For example, ghaf trees are aesthetically pleasing and fast growing, with low water demands. They are excellent for street planting and screening. Freshwater pools, especially if reed beds are allowed to develop, attract a wide variety of birds and insects. Every effort should be made to avoid the overexploitation and use of freshwater, a valuable resource in a desert country. In the case of greening shoreline developments, problems associated with irrigation, including run-off and eutrophication of the channels and khors, should be avoided by use of salt and heat tolerant species that use minimal quantities of water. Insecticide spraying should be avoided as it affects beneficial insects involved in natural pest control as well the nuisance value insects.

Invasive alien species

Intentional or accidental introduction of alien or non-native species of fauna and flora into areas where they are not normally found can be a significant threat to biodiversity, since some alien species can become invasive, spreading rapidly and out-competing native species. Hence it should be a requirement that developers do not deliberately introduce any alien species with a high risk of invasive behaviour, or any known invasive species, and will exercise diligence to prevent accidental or unintended introductions.

Invasive plant species most likely to affect the many sites in the UAE is mesquite, *Prosopis juliflora* or *P. pallida* (Pasiecznik et al. 2001). These South and Central American species are highly invasive and have already colonized areas of the Emirates (El-Keblawy and Al-Rawai 2007). Extreme care should be used that these species are neither deliberately nor accidentally further introduced into this area. *Prosopis juliflora* is a fast growing, salt-tolerant and drought-tolerant tree that can grow in areas receiving as little as 50 mm of rainfall per year. There is great concern surrounding *Prosopis juliflora*: unmanaged, it often colonizes disturbed, eroded and over-grazed lands, forming dense impenetrable thickets. The dense shade and allelopathic chemicals prevent germination and growth of other plant species. *Prosopis* species have been declared noxious weeds in many countries, including Argentina, Australia, South Africa, Pakistan and Sudan and efforts have been made to control the spread of *P. juliflora* in the UAE and Oman. *Prosopis juliflora* is likely to be in competition with the native *P. cineraria* and *Acacia* species, to the detriment of the range of native organisms they support.

In addition, the pollen from this species is highly allergenic (Killian and McMichael 2004), and UAE studies showed that mesquite was the most common cause of allergic reaction (Bener et al. 2002). It is important that all individuals of this species are removed and that the species is not used in landscaping.

Enclosed animals

Larger animals on a site under development should have provision to leave the site. The site should not be entirely fenced until it is certain that any gazelle have left the area and fences should allow for smaller animals such as hares and foxes to pass through.

Off-site mitigation

A variety of off-site strategies are available, where impacts are mitigated on other property. For example, a developer whose proposed development will result in loss of habitat for endangered or protected species, may be required to fund conservation for the protection of an equivalent amount of similar habitat off the site. Such land may be purchased and donated to a private or governmental organisation to be maintained as a protected area, or funding may be paid as in-lieu fees to protect biodiversity reserves. This is a potentially effective and low-risk strategy, but one that has not yet been adopted in the UAE. If such a strategy is used, it is important to ensure that sufficient funding is provided to maintain the protected site, which may require setting up a suitable endowment. Alternatively developers may be required to provide funding for protecting, restoring or enhancing existing protected areas. Degraded land could be restored and habitats recreated, perhaps using top soil skimmed from the development site.

Another strategy is for developers to be required to fund research into biodiversity issues or ecological management so that future mitigation efforts are more effective. In the UAE, where the level of biological and ecological knowledge of most species and ecosystems remains rudimentary, this strategy could provide valuable insights and significantly contribute to biodiversity conservation practice. In practical terms, this could involve funding recognised experts to conduct focussed projects on particular taxa, funding doctoral and post-doctoral research, development of biodiversity action plans, development of management plans for protected areas, research towards producing data-based Red Lists of species of conservation concern amongst others. Such research should be conducted in partnership with local universities and agencies to help build local conservation capacity. For example, although no insects in the UAE are formally recognised as being endangered, this partly reflects the poor state of knowledge of the insect fauna despite two recent publications, which have added more than 500 new species for the UAE (Howarth and Gillett 2008, van Harten 2008). Insects play a crucial role in the maintenance of the food chains and in pollination of the vegetation. In conjunction with the local authority charged with protection and conservation, developers could undertake sponsorship of environmental awareness and education campaigns involving billboards, posters and leaflets explaining the importance of protecting the unique fauna and flora of the Emirates.

In general, the success of any mitigation strategy put forward as part of the EIA will only be as good as the research it is based on, the willingness of the relevant competent authorities, both local and federal, to implement the law in the allocation of development permits, and the degree of compliance with the mitigation strategies on the part of the developers. At present there is considerable variation among emirates within the process, and in the extent to which the developers and competent authorities are independent bodies. There is a rapidly growing sense of the importance of environmental issues in the country, with the development of a carbon-free city in Abu Dhabi (the Masdar initiative), green building design and modern waste disposal methods. It is to be hoped that effective ecological mitigation and biodiversity conservation will now become a higher priority in the development of the nation.

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References

Bener A, Safa W, Abdulhalik S, Lestringant GG (2002) An analysis of skin prick test reactions in asthmatics in a hot climate and desert environment. Allergie et Immunologie (Paris) 34:281-286.

Böer B (1997) An introduction to the climate of the United Arab Emirates. Journal of Arid Environments 35(1):3-16.

Bullock JM (1998) Community translocation in Britain: Setting objectives and measuring consequences Biological Conservation 84(3):199-214.

Dubai Municipality Environment Department (nd) Technical guideline on capture, rescue, translocation / release and restoration of wildlife in the Emirate of Dubai. (draft), Department Municipality, Dubai.

El-Keblawy A, Al-Rawai A (2007) Impacts of the invasive exotic *Prosopis juliflora* (Sw.) D.C. on the native flora and soils of the UAE. Vegetatio 190:23-25.

Fischer J, Lindenmayer DB (2000) An assessment of the published results of animal relocations Biological Conservation 96(1):1-11.

Gardner AS, Aspinall S (2006) Baseline Ecological Survey of the Jebel Ali Airport City site, for Dome International., Dubai.

Gardner AS, Howarth B (2007) Ecological Survey of the route of the proposed Arabian Canal: a report to Tebodin, Dubai.

Germano JM, Bishop PJ (2009) Suitability of Amphibians and Reptiles for Translocation. Conservation Biology 23(1):7-15.

Global Footprint Network (2008) Footprint for Nations: 2008 data tables. Global Footprint Network, Oakland, California, USA.

Harris JA, Birch P, Short KC (1989) Changes in the microbial community and physio-chemical characteristics of topsoils stockpiled during opencast mining. Soil Use and Management 5:161-168.

Harris LD, Gallagher PB (1989) New initiatives for wildlife conservation: the need for movement corridors., in *Preserving communities and corridors*, Mackintosh G ed., pp 11-34. Defenders of Wildlife, Washington D.C.

Howarth B, Gillett M, P.T. (2008) The Terrestrial and Freshwater Arthropods of Abu Dhabi Emirate, in *Terrestrial Environment of Abu Dhabi*, Perry R ed. Environment Agency Abu Dhabi, Abu Dhabi.

Hunter F, Currie JA (1956) Structural changes during bulk soil storage. Journal of Soil Science 7:75-79.

IUCN/SSC Re-introduction Specialist Group (1998) *IUCN Guidelines for Reintroductions.* IUCN, Gland (Switzerland) and Cambridge.

Killian S, McMichael J (2004) The human allergens of mesquite (*Prosopis juliflora*). Clinical and Molecular Allergy 2.

Noss RF, Harris LD (1986) Nodes, networks and MUMs: preserving biodiversity at all scales. Environmental Management 10:299-309.

Pasiecznik NM, Felker P, Harris PJC, Harsh LN, Cruz G, et al (2001) *The Prosopis juliflora - Prosopis pallida complex: a monograph.* HDRA, Coventry, UK.

Van Harten A (2008) *Arthropod Fauna of the UAE, Volume 1.* Dar al Ummah.

Vécrin MP, Muller S (2003) Top-soil translocation as a technique in the re-creation of species-rich meadows. Applied Vegetation Science 6(2):271-278.

Young TP (2000) Restoration ecology and conservation biology. Biological Conservation 92(1):73-83.

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REVIEW ARTICLE

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The Key Biodiversity Areas Project in Iraq: Objectives and scope 2004–2008

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Abstract

Nature Iraq conducted biological surveys throughout Iraq during the 2004 to 2008 period under the Key Biodiversity Areas (KBA) Project. This continuing initiative comprises the largest and most comprehensive biological surveys to take place in Iraq in well over 25 years. Under the KBA Project in Iraq, Nature Iraq in cooperation with the Iraqi Ministry of Environment, has visited over one hundred sites in southern Iraq and in Kurdistan in northern Iraq to survey plants, fish, reptile, bird and mammal species. In addition, water quality physical parameters, sediment, plankton and benthic invertebrates were examined at these sites to determine the overall health of key habitat areas. Birds have been a primary focus of the surveys. This has involved the collection of data on these potential sites of key biological diversity including the identification of species, population counts and information on how species are using a site (e.g. breeding, feeding, migration, etc.). This paper provides an overview of this continuing project that will, over time, permit the refinement of data and the survey of more of Iraq as security improves within the country. The paper also summarizes current recommendations for the management of some of the KBA sites in Iraq.

Keywords

Key Biodiversity Areas, biodiversity surveys, Kurdistan, southern Iraq

Introduction

The marshes of southern Iraq have faced significant environmental change in the last 20 years, as documented by the United Nations Environment Program, UNEP (Partow 2001). This was driven by government-directed drainage of the marshes that caused extreme changes in water quality, biota and, most importantly, the lives of several hundred thousand local people. The severe impact on people has been documented by the AMAR International Charitable Foundation (Nicholson and Clark 2002). The marshes were also affected over this time by the reduction in water flow into the Euphrates and Tigris rivers through construction of hydroelectric and reservoir facilities throughout the countries of the Tigris-Euphrates Basin (Iran, Iraq, Kuwait, Syria and Turkey).

It is estimated that, within only a few years, up to 90% of the original wetland area of the southern marshes of Iraq was turned into semi-desert. The systematic drainage of these marshes impacted all aspects of the biological system - noticeably the bird, fish, plant and other wildlife species of the area. Since 2003, however, up to 58% of these marshes had been re-flooded (as of August 2007), helping to restore the ecological and human socio-cultural web of the region.

It is not known if this re-flooding can be considered sustainable due to the uncertainty of water availability year-to-year in Iraq. For several years, water levels had been favorable, in part due to high seasonal snowfalls in neighboring nations and in northern Iraq, the source areas of much of the water available to the marshes (Alwash Iraq Foundation, personal communication, 2005; Partow, UNEP, personal communication 2005). However, in 2008 water levels in the Marshland areas declined due to drought conditions.

During the 1980 to 2003 period, assessment of the impacts on wildlife populations was not feasible. Surveys to capture biodiversity data have now resumed as an important component of the programs of Nature Iraq in association with Italian, Canadian and other funding agencies. This work was directly implemented in concert with the Iraqi government, non-government organizations (both inside Iraq and internationally) and university partners. This support has increasingly enabled capacity building and training projects (such as reported by Evans 2004, and Porter and Scott 2005) over the 2004 to 2008 period for Iraqi scientists and managers who seek to restore the ecological character of the southern marshes of Iraq. Work was also initiated in Kurdistan in northern Iraq in the winter of 2007. The Nature Iraq KBA project has assisted in the generation of better understanding of biodiversity and management needs, and the implementation of wildlife surveys, monitoring programs and marshland restoration and management initiatives in Iraq.

This paper summarizes a more detailed report submitted to the Government of Iraq (Rubec and Bachmann 2008). It is hoped that this paper and its associated report will collectively assist in the conservation of the marshes by increasing cooperation between government, non-government and university stakeholders in Iraq.

The Key Biodiversity Areas Program

The development of reliable information on the status of the Key Biodiversity Areas of Iraq is designed to support long-term restoration and management planning for important habitats such as the southern marshes of the country. The definition of "Key Biodiversity Areas" closely follows that developed and implemented by BirdLife International (BLI) with national partner agencies, including Nature Iraq, in several countries. This definition recognizes that biological richness and importance are "more than birds", thus extending the highly successful BLI international program for Important Bird Areas (IBAs). The KBA program in Iraq, as discussed below, builds on the IBAs Program led in many countries by BirdLife partner organizations. The Mesopotamian Marshes for example support at least 34 species of conservation concern including eight globally threatened bird species (Salim et al. 2009, this volume) including endemics such as the Iraq Babbler and the Basra Reed Warbler (Stattersfield et al. 1998).

Objectives

The objectives of the KBA field program are:

- To undertake annual winter surveys (between the months of December and February 2005 to 2008) and annual summer surveys (between the months of May and July 2005 to 2008) of as many of the KBA sites as possible;
- To record information on the status of habitats and threats to these sites;
- To provide advice to the Ministry of Environment and other Iraqi stakeholders on the future management relevant to restoration of healthy ecosystems and communities of each KBA site; and
- To publish relevant scientific and technical papers and reports on this work.

KBA Sites

Early on in this Project, decisions had to be made as to which sites would be the focus of the field studies. It was agreed to build upon known, published information on sites of biodiversity interest in Iraq. The chosen locations for KBA field studies were initially based on the Important Bird Areas (IBAs) of Iraq as published by Evans (1994) and supplemented by a listing of potential Wetlands of International Importance (meeting thus the site criteria of the Ramsar Convention) in Iraq by Scott (1995).

Building upon the same basic principals as IBAs but not restricted just to bird species, KBAs are seen as the building blocks of landscape-level conservation planning, according to the World Conservation Union (IUCN 2007).The Iraqi KBAs are thus considered to be sites of global significance for biodiversity conservation as they readily meet the IUCN criteria based on a framework of vulnerability and irreplaceability (IUCN 2007).

Under vulnerability criteria, any sites where critically endangered, endangered or vulnerable species occur can be listed as a KBA site. Irreplaceability criteria are concerned with those sites that hold restricted-range species, species with large but clumped distributions, globally significant congregations, globally significant source populations and bioregionally-restricted assemblages.

Within the southern marshes of Iraq, Key Biodiversity Area (KBA) sites that were chosen are those previously known to be particularly important for breeding and wintering birds and that had been the subject of re-flooding since 2003. A total of 43 possible KBAs were thus selected in Iraq. Of these KBA sites, 26 are located in southern Iraq (see Fig. 1 and Table 1 below). Sites numbered 17 to 42 were the initial focus of the southern field program. These sites occur mainly in the south and are concentrated in Missan, Thi Qar and Basrah Governorates. Four sites were located in Kurdistan in northern Iraq (one of these represents three distinct areas) in the governorates of Sulaimani, Erbil and Dohuk and were first surveyed in the winter of 2007.

Due to the extensive time that had passed since these sites had been initially visited and/or evaluated as IBA sites, it is now accurate to call them potential KBA sites. Most of the sites had not been surveyed since at least 1979 or earlier. Upon evaluation of these sites, it was felt that some might no longer meet IBA and KBA criteria due to extensive ecological damage or change. It was also recognized from the outset that security conditions, military restrictions, and other factors could significantly affect the planning and access to sites in this project. Thus, it was not expected that all potential KBA sites might be fully surveyed, as would be ideal. Indeed, due to these types of limitations, no work was done at several of the listed sites (particularly No. 017, 018, 019, 020, 021, 022, and 027). KBA sites numbered 001 to 016 lie in the northern and western areas of Iraq and were deemed beyond the scope of the initial work. However, several of these sites (Sites 001, 002, 003, 004a, b, c as well as Mosul Lake) are now included in the field program in the Kurdistan Region of northern Iraq. Additional sites were added based on local knowledge and stakeholder input and are to be considered potential KBA sites until a final assessment is complete. Marine sites at the mouth of the Shatt al-Arab are also known to have high biodiversity value particularly for avian species. However, the extreme sensitivity of this military zone has precluded most scientific work in the immediate area beyond several Shatt al-Arab sites (No. 40–42) visited sporadically to date by Nature Iraq (see Fig. 1, Table 1).

Field study locations

An initial February to March 2005 survey was restricted to seven KBA sites in southern Iraq. It was limited by practical and security issues in that period and seen as a start-up, experience-building exercise. However, useful data were collected nonetheless. The winter of 2005 survey included portions of KBAs No. 030, 032, 033, 034, 036, 038 and 039 (see Table 1). All other southern KBA sites were included in the subsequent surveys, except where security concerns interfered.

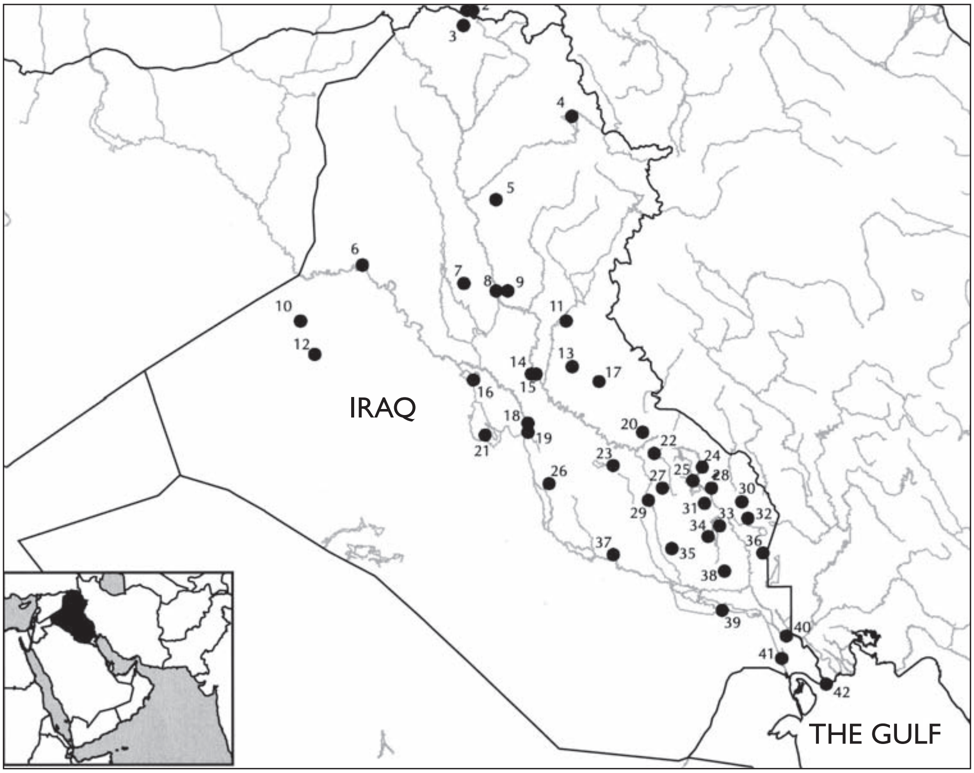

Figure 1. Map of the IBAs of Iraq, From Evans (1994).

In order to facilitate field survey logistics, seven major wetland areas in the south were defined (Figs 2 and 3 show two examples of these areas): Hammar Marshes (HA), Central Marshes (CM), Hawizeh Marshes (HZ), Middle Euphrates Marshes (ME), Seasonal Marshes (SM), Shatt Al Arab Marshes (SA), Khor Az Zobayr Marshes (KZ). In Kurdistan, northern Iraq, sites were organized by Governorate (Figs 4 and 5 show two examples of these areas): Sulaimani (S), Erbil (E), Dohuk (D). These areas are all identified on the map in Fig. 6.

Biodiversity observations

The KBA team recorded field observations during winter and summer in 2005, 2006, 2007 and 2008 that focused on birds, fish, zooplankton, macrophytes, phytoplankton, sediments and water quality. Anecdotal mammal, reptile and amphibian observations were also included. In 2008, the southern survey was reduced to bird, habitat and vegetation surveys. Papers and reports on these surveys are currently in preparation or in press.

Table 1. Key Biodiversity Areas Iraq visited by KBA the Team (after Evans 1994 and Scott 1995).

Site Name and Code*	Area (ha)	Latitude/ Longitude	Habitat Type	Governorate
Kurdistan Sites				
IBA 001. Beanavi (Benavi)	600	37°20'N, 42°35'E	Rocky wooded valley	Dohuk
IBA 002. Dori Serguza	400	37°13'N 43°28'E	Valley with springs and woodland	Dohuk
IBA 003. Ser Amadiya (Ser Amadia)	6,500	37°10'N, 43°22'E	Cliffs and valleys	Dohuk
Scott: Aski Mosul Reservoir (Great Saddam Lake) (not listed as IBA in Evans, 1994)	Lake is 30 km long	36°32'N, 42°45'E	Reservoir	In North near Mosul
IBA 004. (a) Bakhma, (b) Dukan and (c) Darbandikhan Dams;	40,000	36°10'N, 44°55'E	Reservoirs, flood plain and valleys	Dohuk, Erbil, and Sulaymaniyah
Scott: Dukan Reservoir	25,000 ha lake which is 30 km long by 15 km wide	36°10'N, 44°55'E		
Scott: Darbandikhan Reservoir	7,500 ha lake which is 30 km long by 10 km wide	35°10'N, 45°50'E		
Sites in Southern Iraq				
IBA 023. Hor Delmaj; Scott # 14. Hor Delmaj (Dalmaj Marsh)	100,000	32°20'N, 45°30'E	Freshwater lake	Wasit
IBA 024. Hor Sarut;	50	32°19'N, 46°46'E	Reedbed and lake	Missan
Scott # 21. Hor Sarut (Saaroot)	Not listed	32°07'N, 46°46'E		
IBA 025. Hor Al Sa'adiyah; Scott # 20. Hor Al Sa'adiyah (Sa'diya)	140,000	32°10'N, 46°38'E 32°01'N to 32°25'N; 46°22'E to 46°44'E	Freshwater lake	Wasit
IBA 026. Hor Ibn Najim; Scott # 12. Hor Ibn Najim (Ibn Najm Marsh)	10,000	32°08'N, 44°35'E	Seasonal freshwater lake	Babil
IBA 028. Hor Al-Haushiya - Al Kumait Ponds, Ali Sharqi Ponds;	200	32°05'N, 46°54'E	Artificial ponds	Missan
Scott # 22. Hor Al Haushiya	Not listed			
IBA 029. Shatt Al Gharraf;	125+	31°57'N, 46°00'E	Ponds and seasonal wetlands along a waterway	Wasit and Thi Qar
Scott # 18. Shatt Al Gharraf (Gharraaf River)	not listed			
IBA 030. Hor Chibayish Area; Scott # 23. Hor Chubaisah Complex (Sinnaaf Area)	27,500	31°56'N, 47°20'E 31°53'N, 47°18'E	Freshwater lakes and marshes	Missan
IBA 031. Hor Sanniya; Scott # 24. Hor Sanniya (Saniya)	40,000	31°55'N, 46°48'E	Freshwater lakes	Missan

Site Name and Code*	**Area (ha)**	**Latitude/ Longitude**	**Habitat Type**	**Governorate**
IBA 032. Hor Om Am Nyai -Suweid, Sudan Marshes; Scott # 29. Suweid Marshes (Umm An Ni'aaj)	15,000	31°45'N 47°25'E	Wetlands and open water	Missan
IBA 033. Hor Al Rayan and Umm Osbah - Maymund and Salam Marshes; Scott # 25. Hor Al Rayan and Hor Umm Osbah (Rayan)	25,000	31°40'N, 47°01'E 31°53'N, 47°02'E	Sedge marsh, lagoons and reedbeds	Missan
IBA 034. Hor Auda; Scott # 26. Hor Auda (Auda Marsh)	7,500	31°33'N, 46°51'E	Freshwater marshes and lakes	Missan
IBA 035. Hor Uwainah - Shatra Marshes; Scott # 19. Hor Uwainah - Shatra or Chamuqa Marshes (U'wainah Marsh near Shatra)	32,500	31°25'N, 46°20'E	Lakes and marshes	Thi Qar
IBA 036. Hor Al Hawizeh - Hor Al Azim in Iran portion Scott # 30. Hor Al Hawizeh (Hawizeh Marshes)	220,000	31°22'N, 47°38'E 31°00'N to 31°45'N; 47°25'E to 47°50'E	Freshwater marshes	Missan, Basrah
IBA 037. Hor Lafta Scott # 13. Hor Lafta (Lafta Marsh)	20,000	31°21'N, 45°30'E	Isolated freshwater lake on saline plain and dunes	Muthanna
IBA 038. Central Marshes - Amara Marshes Scott # 27. Central Marshes	300,000	31°10'N, 47°05'E 30°50'N to 31°30'N'; 46°45'E to 46°25'E	Open water and freshwater marshes	Missan, Thi Qar, Basrah
IBA 039. Hor Al Hammar Scott # 28. Hor Al Hammar (Hammar Marshes)	350,000	30°44'N, 47°03'E 30°35'N to 31°00'N; 46°25'E to 47°45'E	Marshes and lakes	Thi Qar, Basrah
IBA 040. Shatt Al Arab Marshes Scott # 31. Shatt Al Arab Marshes	165 km length of river	30°27'N, 47°58'E Stretches from 31°00'N, 47°25'E to 29°55'N, 48°30'E	Riverine floodplain wetlands and reed marshes	Basrah
IBA 041. Khor Al Zubair Scott # 32. Khor Zubair (Khor Al Zubayr)	20,000	31°12'N, 47°54'E	Tidal inlet and intertidal mudflats	Basrah
IBA 042. Khor Abdallah Scott # 33. Khor Abdalah and the Fao Area	126,000	29°55'N, 48°32'E	Swampy grass flats (90,000 ha) and intertidal mudflats (36,000 ha)	Basrah

*IBA numbers refer to Evans (1994) numbering system, Scott number refers to Scott (1995) numbering system. Name in parentheses, where present, represent the Nature Iraq name for the site.

Figure 2. Central Marshes (CM), December 2007 (photo M. Shebel).

Definition of management issues

In November 2004, a workshop was organized with Iraqi specialists in environmental management as part of a training course for prospective KBA team members (Evans 2004). A priority setting exercise on the status and management options for KBAs in Iraq was conducted.

Participants expressed their views with regard to the marshes of Iraq. The various views highlighted the richness of natural and cultural resources in the area. In 2004, they felt that law enforcement was a key element for the conservation successes as this had previously proved effective in Iraq. However, due to the politically unstable conditions that much of Iraq is now witnessing, these enforcement efforts have virtually collapsed.

Participants suggested a series of management options for KBA sites, including:

- Establish a support group or council at each KBA for enhancing conservation and sustainability;
- Enhance the roles and involvement of local communities in decision-making;
- Involve various governmental institutions;
- Promote job creation;
- Promote landscape restoration;
- Undertake awareness building;

Figure 3. Hammar Marshes (HA), December 2007 (photo M. Shebel).

– Ensure improved project coordination;
– Build political and cultural support.

There was strong agreement between participants that the marshes faced a wide array of threats, including:
– Fires;
– Date palm plantation removal;
– Dumping and waste accumulation;
– Construction of dams and impoundments;
– Unsustainable agricultural, hunting and fishing practices;
– Water pollution;
– Wildlife disturbance during breeding seasons;
– Habitat loss and fragmentation;
– Road construction and industrial development;
– Lack of legal land titles.

It was indicated that there should be a mechanism for conflict resolution with local communities. This could be based on the number of affected families and type of lost

Figure 4. Peramagroon Mountain, January 2008, Sulaimani – S (photo K. Ararat).

opportunities for that local community. Also, it was pointed out that there was a need to have a National Wetland Strategy and national accession to the Ramsar Convention on Wetlands (which took place in Iraq in 2007). Integration within other global conventions such as the Convention on Biological Diversity could also provide a strong advocacy tool. Discussions shed light on identification of the marshes as a special development area. Participants also agreed that attention should be made to transboundary management issues for the Hawizeh Marsh (e.g. for the marshes area shared with Iran) to address threats to the ecological character of this area. Hawizeh Marsh is now Iraq's first Ramsar site and a draft management plan has been completed for the area (Rubec 2008).

Discussion of management recommendations for southern KBA sites

Conservation actions that are recommended for each of the priority categories, using a weighted point assignment process developed at the 2004 workshop (Evans 2004) are presented below in Table 2. In addition, a summary of the KBA sites felt to be "critical", "urgent" or "high" in terms of conservation priority and notes on the current habitat conditions at surveyed sites are presented in Table 3. The sites are thus ranked as: Critical priority sites that require intensive and immediate action (over 39 points);

Figure 5. Gara Mountain, March 2007, Dohuk – D (photo by K. Ararat).

Urgent priority sites that require ongoing action at a less intensive level (30–39 points); or High priority sites that require lower-level actions (20–29 points).

Conclusions

Comprehensive ecological survey work is still not possible in all areas of Iraq due to security concerns over much of the country. Hence, many sites cannot be visited or visited systematically. Often those sites that are visited cannot be completely assessed due to restrictions on available time or other logistical concerns related to security problems. Despite these factors, the Nature Iraq KBA work has been an important step in assessing Iraq's biological diversity. Over time, this will benefit the conservation and management of this national resource. Nature Iraq has collected valuable data on important ecosystems now in the process of undergoing extensive ecological recovery after decades of degradation and destruction.

The data collected over the past four years and from up-coming surveys will provide critical information as Iraq engages the international community in agreements such as the Convention on Wetlands (Ramsar Convention), the Convention on Biological Diversity (CBD), the Convention on the International Trade of Endangered Species

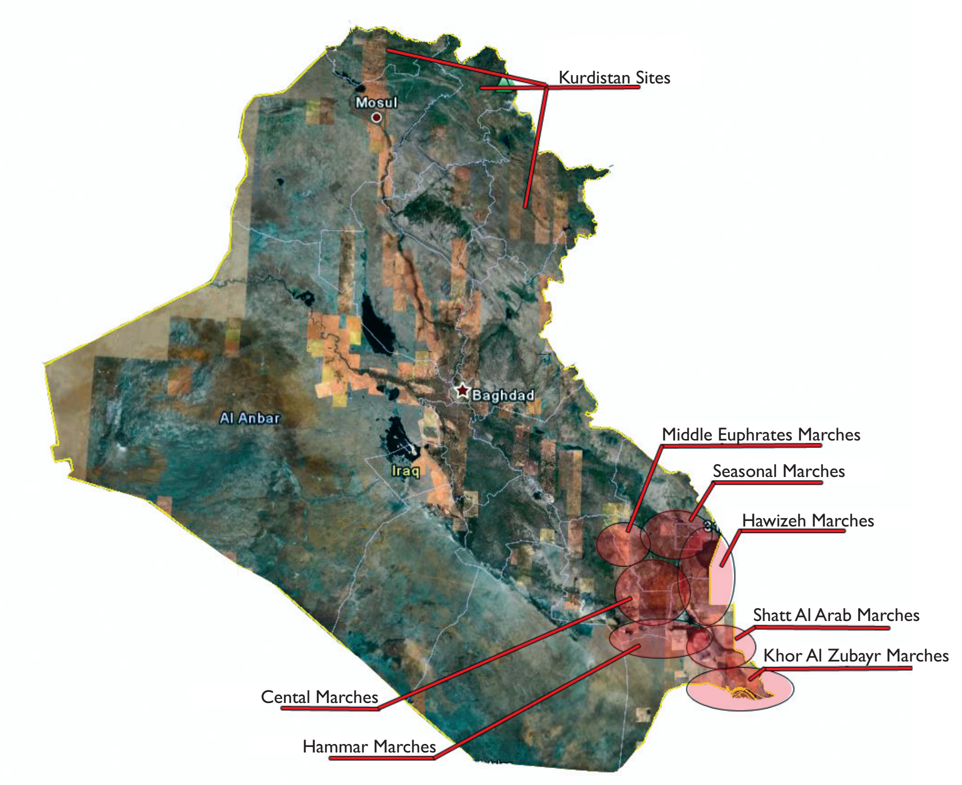

Figure 6. The seven major wetland survey areas of southern Iraq and the locations of survey sites in Kurdistan, northern Iraq.

Table 2. Recommended conservation actions for all sites.

Critical Sites	Critical and Urgent Sites	Critical, Urgent and High Priority Sites
Identify actual and potential stakeholders for KBA conservation	Develop and maintain Site Support Groups	Monitoring
Provide alternatives for local communities living in and around KBAs, through promotion of Site Support Groups	Socio-economic surveys	Awareness raising for decision-makers
Conservation projects	Education and awareness raising	Enforce conservation policies
Integrated resources and ecosystem management	Local and national advocacy for IBA conservation	Promote ecotourism
Develop and implement management or action plans	--	Advocacy for protection status
Land purchase or rental	--	Detailed surveys
Habitat restoration and rehabilitation	--	Lobby for appropriate legislation on site conservation

Table 3. Summary of 2004 conservation rankings for KBAs in Iraq based on threats and biological importance for birds, and 2008 current habitat status.

IBA Site No. and Name*	**2004 Total Points Ranking For Conservation Action**	**2004 Categorization**	**Current Habitat Status (2008)**
KBA sites assessed in 2004 conservation ranking exercise			
022. Hor al-Abjiya and Hor Um al-Baram	25	High	Unknown
024. Saaroot	21	High	Seasonally flooded in 2005, 2006, 2007
025. Sa'idya	26	High	Dry, now used for agriculture
027. Hor al-Hachcham and Hor Maraiba	26	High	Unknown
028. Hor al-Haushiya	25	High	Dry with saline soils and halophytic vegetation. Poor security.
030. Sinnaaf	25	High	A dry site with occasional winter flooding
031. Saniya	28	High	Dry with high security risks
032. Umm An Ni'aaj	31	Urgent	Brackish water marsh (fresh waters in some areas in winter) with good plant, fish and bird diversity
033. Rayan	33	Urgent	Flooded in 1st survey, dry in 2nd survey
034. Auda Marsh	34	Urgent	Flooded but affected by eutrophication because of lack of water flow-through
035. Al Shatrah - West of Al Riwaiya (Hor Uwainah)	33	Urgent	Dry site with high security risks
036. Hawizeh Marshes	41	Critical	Flooded
038. Central Marshes	39	Critical	Shallow waters with very poor quality
039. Hammar Marshes	46	Critical	West portion flooded; centre portion is now a small lake; east portion is flooded tidally
KBA Sites Not Assessed in 2004 Conservation Ranking Exercise			
001. Benavi		--	Forested mountain site
002. Dori Serguza		--	Forested mountain site in Dohuk governorate – not assessed & has incorrect gps location.
003. Ser Amadia		--	Forested mountain site
004. Bakhma, Dukan and Darbandikhan		--	Bakhma-Big Zap River with incomplete dam structures; Dukan and Darbandikhan – Large reservoirs
Mosul Lake		--	Large reservoir

IBA Site No. and Name*	2004 Total Points Ranking For Conservation Action	2004 Categori-zation	Current Habitat Status (2008)
023. Dalmaj Marsh	--	--	Flooded/Current Status Unknown
026. Ibn Najm	--	--	Flooded
029. Gharraf River	--	--	Flooded
037. Lafta Marsh	--	--	Dry/Current status unknown
040. Shatt al-Arab Marshes	--	--	Flooded
041. Khor al-Zubayr	--	--	Marine
042. Khor Abdallah	--	--	Marine/Current status unknown

*Using Evans (1994) site codes and Nature Iraq site names (where assigned).

(CITES), the Convention on Migratory Species (Bonn Convention) and others. Nature Iraq will continue to maintain and update information on these and other sites within the country and will make data available to the Iraqi government, stakeholders and other interested organizations and agencies concerned with biodiversity in Iraq.

The biological diversity of the country is not contained within Iraq alone but is shared with the region and the globe. As a result, Nature Iraq will be incorporating many of its key observations into internationally shared sources such as the Worldbird Middle East Database, an Internet-based spatial database about birds provided by the Royal Society for the Protection of Birds (United Kingdom) and BirdLife International. Through these and other methods, Nature Iraq hopes to share information, resources and expertise with regional and international organizations that can assist as partners with Iraqi conservation efforts.

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References

Evans MI (1994) Important Bird Areas in the Middle East. BirdLife Conservation Series No. 2. Cambridge, United Kingdom: BirdLife International.

Evans MI (2004) Saving Mesopotamian Marshes of Iraq, Environmental Training Programme for Iraqi Biologists – Study Tour of Jordan November 22–29 2004. Canada-Iraq Marshlands Initiative, Technical Report No. 2. Waterloo. Canada: University of Waterloo.

IUCN (2007) Identification and Gap Analysis of Key Biodiversity Areas: Targets for Comprehensive Protected Area Systems. Best Practice Protected Area Guidelines Series No. 15. Peter Valentine (Ed) Gland, Switzerland: International Union for Conservation of Nature and Natural Resources.

Nicholson, E and Clark, P (Eds) (2002) The Iraqi Marshlands: A Human and Environmental Study. Second Edition. London, United Kingdom: The AMAR International Charitable Foundation.

Partow, H (2001) The Mesopotamian Marshlands: Demise of an Ecosystem. Division of Early Warning and Assessment. Nairobi, Kenya: United Nations Environment Program.

Porter RF, Scott DA (2005) Report on the Environmental Training Programme for Iraqis and Birds Recorded in Syria – January 20–29, 2005. Canada-Iraq Marshlands Initiative, Technical Report No. 3. Waterloo. Canada: University of Waterloo.

Rubec CDA (2008) Management Plan for the Hawizeh Marsh Ramsar Site of Iraq. Draft Report. Sulaimani, Kurdistan, Iraq: Nature Iraq and the Iraq National Marshes and Wetlands Committee.

Rubec CDA, Bachmann A (2008) The Key Biodiversity Areas Program in Iraq: Objectives and Scope 2004–2008. Project Report. Sulaimani, Kurdistan, Iraq: Nature Iraq.

Salim M, Porter R, Clayton R (2009) A summary of birds recorded in the marshes of southern Iraq, 2005–2008. In: Krupp F, Musselman JL, Kotb MMA, Weidig I (Eds) Environment, Biodiversity and Conservation in the MiddleEast. Proceedings of the First Middle Eastern Biodiversity Congress, Aqaba, Jordan, 20–23 October 2008. BioRisk 3: 205–220.

Scott DA (1995) A Directory of Wetlands of the Middle East. Slimbridge, United Kingdom: International Waterfowl and Wetlands Research Bureau.

Stattersfield AJ, Crosby MJ, Long MJ, Wege DC (1998) Endemic Bird Areas of the World - Priorities for Biodiversity Conservation. Conservation Series No. 7. Cambridge, United Kingdom: BirdLife International.

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RESEARCH ARTICLE

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Habitat mapping project of the proposed Iraqi Marshlands National Park area

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Abstract
New ecological surveys in support of the creation of the proposed Iraqi Marshlands National Park were undertaken by Nature Iraq in June 2008 at the Central Marshes in southern Iraq. Surveys that occurred in two focal areas - Al Chibaish Marsh (10 sites) and Abu Zirig Marsh (two sites) - were supported by a preliminary land cover survey in November 2007. Satellite images from 2007 for the Central Marshes were acquired to support creation of maps. The "Iraqi Marshlands Habitat Classification System" based on vegetation types has been developed to inventory habitats in these marshlands and to develop a methodology for application elsewhere in Iraq. Six habitat classes (inland running water, river or canal; inland standing water; marsh vegetation; desert; woodlands; and herbaceous vegetation) are included in this classification system, each of which is divided into several subclasses. The dominant habitat subclasses in the Central Marshes study area are: (1) rooted submerged vegetation, (2) helophytic vegetation (reed bed or reed mace bed), (3) free-floating vegetation, (4) terrestrial vegetation-shrub, (5) unvegetated river or canal, (6) unvegetated desert, and (7) flooded communities. This paper constitutes a review of the progress in developing this habitat classification system that remains under development.

Keywords
Habitat mapping, Iraqi marshlands, marshland restoration

Introduction

The Government of Iraq is currently considering the establishment of a new National Park in a portion of the Central Marshes of southern Iraq. A "Draft Management Plan for the Central Marsh National Park, Iraq" has been developed (New Eden Group 2008). To assist in this planning process, a baseline habitat survey was deemed to be essential. Thus, in 2007 Nature Iraq with the financial support of the Italian Ministry of Environment, Land and Sea initiated a project to identify, survey and map habitats in the area of the proposed park in collaboration with the Iraq Ministry of Environment. This habitat project is also related to other projects that Nature Iraq is carrying out (such as the completion and implementation of a Management Plan for the Hawizeh Marsh, Iraq's first Wetland of International Importance designated under the global Ramsar Convention in 2007; Rubec 2008). This paper discusses the national park habitat mapping project.

The classification of vegetation types is usually achieved through the grouping of similar types of vegetation according to logical criteria (Sayre et al. 2000). One of the first attempts to classify marsh habitats was Warming (1909) in his book "Oecology of Plants" which identified two major types of wetland depending on plant communities: Saline swamp (with halophytic vegetation) and freshwater swamp. Mader (1991, cited in Tiner 1999: 258) emphasized that classification should be: (1) Flexible, general, and of wide geographic applicability in order to allow for the prediction of distribution patterns over a range of environmental situations; (2) professionally credible, preferably through experimental validation; (3) based on concepts that are understandable by non-technical people; (4) logical, consistent, and objectively quantifiable so as to function within in empirical computer-operated information system; and (5) designed and documented so that regular professional staff can, with nominal training, use the system to identify and map field sites.

Adaptation of the European Nature Information System (EUNIS) habitat classification (Davies et al. 2004) was chosen as the model for classification of habitats in this project. The EUNIS habitat types are classified hierarchically (Davies et al. 2004). Other habitat classification systems are also organized hierarchically and contain descriptions of the classified units (FGDC 1996, Grossman et al. 1998). Thus, the Nature Iraq team chose to establish Iraq's classification scheme based on vegetation in addition to other criteria and emulate the experience in the references noted here. The Italian partners helped in developing the Iraqi project by assisting with training in the use of the EUNIS system. After field testing, modifications were undertaken to make it more applicable in Iraq's marshlands.

Vegetation is the focal issue in this habitat study of a key area of Iraq's southern marshlands due to the importance of plants as food and shelter for people and wildlife. This is supported by the economic value of many aquatic plants as food or in manufacturing and their role in cleaning water, and because these plants often are indicators of hydrological and environmental conditions at the sites.

In the last few decades at various times (and again in 2008 due to drought), there has been a significant reduction in the water levels in this area of southern Iraq, which has led to a deterioration in water quality and changes in the distribution and status of the biodiversity of the region. Monitoring of the impact of these variations in water conditions has become critical to the marsh restoration efforts in Iraq.

Thus, one of the goals of this project is to improve the monitoring of the Iraqi marshlands. Remote sensing and satellite imaging technology, it was hoped, should improve the efficiency of monitoring field trips and reduce associated cost. Ground-truth field data was essential to developing the classification scheme and to map the habitats. Later, it was also felt that the level of effort to deliver the overall project could be reduced if the satellite images indicated that there was significant change in the study sites and the overall proposed national park area. To carry out this project, the work was divided into three steps: S(I) Discussions and planning; (II) land cover survey; and (III) description and definition of habitats.

Step I included discussions between Nature Iraq, Italian and other international experts about how to carry out the project and what was needed to achieve it. Step I also included the preparation of a work plan, definition of needs and the training of staff. Step II was supported by an initial field trip in November 2007 designed to identify land cover classes in the Central Marsh of the Al Chibaish Marsh area (CM) and the Abu Zirig Marsh area (AZ). For Step III in June 2008, sites were identified as habitats of specific species and described according to water quality, sediments, birds, fish, benthic macroinvertebrates, zooplankton and phytoplankton, plants and habitat characteristics and their status. The "Iraqi Marshlands Habitat Classification System" is gradually being refined, but currently remains provisional.

Additional surveys supporting Step III will cover the environmental parameters that can give Nature Iraq an indication of the environmental or economic values of each habitat subclass. This information will help decision-makers to prepare plans for ongoing marsh restoration and conservation of those sites that are important from an environmental point view, such as the National Park in the Central Marshes and Ramsar sites in Iraq.

Objectives

This project has three objectives:

- To survey and obtain specific data that can support Nature Iraq projects;
- To use standard criteria for describing the status of the marshes in terms of vegetation cover, water quality and biodiversity; and
- To facilitate conservation of these sites.

Materials and methods

Study area

The ground-truth field surveys focused on describing the ecological characteristics and habitat structure at representative sites. All selected sites were within the proposed Central Marshes National Park area and were distributed between the Al Chibaish Marsh area and Abu Zirig Marsh area. Table 1 includes the names, codes and GPS coordinates of each habitat survey site. The exploratory field trip conducted in November 2007 was the starting point of the project. By using satellite images from 2006, an initial land cover survey and water quality study was conducted for nine candidate survey sites in these marshes. There is also data from previous surveys in August 2007 for all of Iraq's southern marshlands and their adjacent areas (Abdulhassan 2007). The most recent survey was in June 2008 (by using another satellite image from 2007) and some of the results of this work are presented in this paper. Twelve sites were surveyed from the 14 to 18 June 2008, ten of which were in Al Chibaish Marsh area and two were in Abu Zirig Marsh area.

Satellite image processing

Remote sensing has long been identified as a technology capable of supporting the development of habitat maps over large areas. Satellite images contain a information regarding land and water characteristics and the application of digital image process-

Table 1. Site names and nodes, and GPS coordinates at Al Chibaish (CM) and Abu Zirig (AZ) for the 14 to 18 June 2008 habitat survey**.**

Area (Central Marsh)	Name of site	Site code No.	GPS soordinates					
			N latitude			E longitude		
			°	'	"	°	'	"
Al Chibaish	Al Baghdadia	HAB-CM-2	47	0	48.3	31	1	26.4
	Al Baghdadia	HAB-CM-5	47	0	52.5	31	2	50.6
	Al Baghdadia	HAB-CM-10	47	2	13.0	31	2	21.0
	Um Lilo	HAB-CM-11	47	2	16.9	31	1	28.7
	Eishan Al-Gubba	HAB-CM-13	47	1	3.6	31	4	10.8
	Core area	HAB-CM-12	46	59	58.8	31	4	32.2
	Core area	HAB-CM-25	46	59	53.9	31	7	49.2
	Core area	HAB-CM-26	46	58	13.7	31	9	44.4
	Zichri	HAB-CM-27	47	13	18.5	31	2	50.3
	Central Marshes (Al Hamar)	HAB-CM-28	46	49	37.3	30	59	21.0
Abu Zirig	Close to Al-Fuhood Town	HAB-AZ-1	46	46	30.1	30	59	4.8
	Close to Al-Fuhood Town	HAB-AZ-3	46	41	18.4	31	0	53.5

ing allows for the extracting of data from a digital image very effectively. In the work, remote sensing activities allowed for survey of the extension and the distribution of the land cover classes of marshes and to ability to analyze the development of wetland vegetation.

A first map of the Central Marshes was created on the basis of SPOT satellite images acquired in July 2006. The pre-processing of SPOT satellite data has included radiometric calibration and atmospheric effect correction (dark object subtraction). Image interpretation and analysis of vegetation indices allowed for the spectral analyses of surfaces and the characterization of the different land cover classes. Then, supervised image classification allowed the creation of detailed land cover maps at the scale of 1:50,000.

In a second phase of the work, ASTER satellite images acquired in July 2007 were processed to obtain updated maps of the study area. The same techniques of image pre-processing and supervised classification used for the SPOT images were applied. The monitoring survey ground-truthing gave parameters necessary to refine and validate the land cover classification obtained from the remote sensing analysis. The final products, based on the "Iraqi Marshlands Habitat Classification System", are land-cover maps at the scales of 1:50,000 and 1:100,000 (see Fig. 1). It is expected that the project can eventually permit effective, low-cost monitoring of these Iraqi marshlands by applying remote sensing and satellite imaging technology.

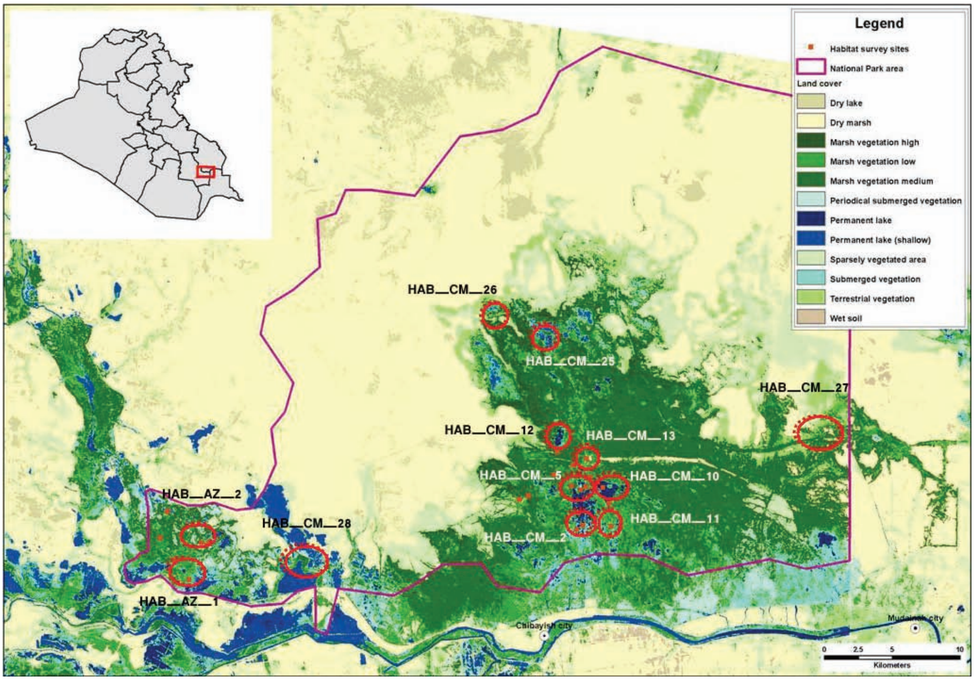

Figure 1. Satellite-based land-cover classification of the Central Marsh (Al Chibaish and Abu Zirig) showing the selected survey sites (circled areas).

The Habitat Hectare Approach (HHA) for assessing habitat

In order to characterize vegetation classes and subclasses of high conservation priority and to gather quantitative data on species richness, plot studies were used (as suggested by Sayre et al. 2000). The number of plots at the site was determined by the range of distinct habitats defined in preliminary classifications of the sites (usually between one and four habitat types). The HHA involves assigning a habitat score to a habitat zone that indicates the quality of the vegetation relative to established benchmarks. This habitat score can then be multiplied by the area of the habitat zone (in hectares) to determine the quality and quantity of vegetation (thus calculating "habitat hectares"). The components are divided into two groups reflecting an assessment of both "site condition" and "landscape context". This is useful for habitat assessment and ground-truthing (DSE 2004). The HHA method was applied in the ground-truthing exercises as a methodology to check the classification of the land-cover classes resulting from remote sensing application. Due to the broader complexity of the HHA method, only the determination of vegetation cover from this method was applied within each hectare and without the scoring (Fig. 2).

Vegetation

Plant genera and species were identified using botanical keys (Townsend and Guest 1966, 1968, 1974, 1980a, 1980b, 1985). The descriptions of aquatic plants were checked using other Iraq-specific references (e.g. Al-Sa'ady and Al-Mayah 1983). Internet botanical resources were also used to confirm the identification of some plant species (Google Image Search 2008). Species were identified in the field where possible or collected in nylon bags, pressed and transferred to the lab for identification with appropriate botanical keys. These specimens are now preserved in Nature Iraq's herbarium in Sulaimani, Iraq.

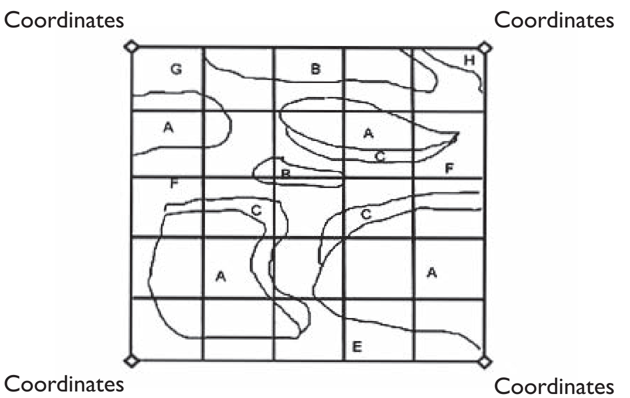

Figure 2. Application of the Habitat Hectare Approach (HHA) method; field data sheet for describing habitats (codes A-F indicate habitat classes).

Photographic records of fresh specimens were also used to aid identification. Percent vegetation cover for each plant species found at each site was estimated (using the HAA method) and used to calculate the total percentage vegetation cover for the whole site.

Results and discussion

Vegetation

The dominant vegetation type at each site was used as the basis for identifying the habitat types. Some plant species were common and found at most of the sites while others were restricted to one or two sites, but most of the identified plants are common in these Iraqi marshes. Some species are native to Iraq such as *Aeluropus lagopoides* that exists near the margins of the marshlands (Townsend and Guest 1968). *Hydrilla verticillata* is known to be an invasive species in some parts of the world and may be a new exotic species in Iraq as it was not mentioned in (Townsend and Guest 1985). Those authors listed only three plant species belonging to Hydrocharitacea of which *Hydrilla verticillata* was not included. It is possible that it was introduced during the period of great ecological change that occurred with the drainage and later reflooding of the marshlands of southern Iraq in the 1990s and after 2003. A noteworthy point about these plant communities is that the reed growth probably expanded in the last few years because of the decrease in water level (those species need a water depth of more than 2 m in the open water areas to avoid reed expansion). This has led to the decrease of total open water area and the closing off of many water passages due to the expansion of reeds. Table 2 provides a listing of the percentage vegetation cover at each of the 12 survey sites examined in June 2008.

Habitat classification system for the southern Marshlands of Iraq

Classification systems have been developed in order to divide habitats into groups with similar features or functions. This is important in Iraq for identifying and describing habitats in order to assess their biodiversity status and habitat functions and then establish conservation plans for Iraq's ecologically important habitats. As in many classification systems, including the EUNIS (Davies et al. 2004), the classification developed for Iraq's habitats is organized hierarchically. It includes a description of the classes and subclasses of habitats. This provisional Iraqi system is modeled only partially on the EUNIS system as some of the classes are chosen while others are not because they are not applicable for Iraq's marshlands. However, even the applicable parts were subjected to some modifications to make them fit more readily with the uniqueness of Iraq's marshlands. For example, the class "permanent lake ice" that is used in the EUNIS system, is excluded from Iraqi marshlands classification system because there is no such habitat in the marshes of Iraq. Also, the class "permanent inland saline and brackish lakes, ponds, and pools" was retained but under the subclass "salt water".

Table 2. Vegetation cover (%) of each of 12 survey sites.

Plant species	HAB-CM-2	HAB- CM-5	HAB-CM-10	HAB-CM-11	HAB-CM-12	HAB-CM-13	HAB-CM-25	HAB-CM-26	HAB-CM-27	HAB-CM-28	HAB-AZ-1	HAB-AZ-2
Aeluropus lagopoides						*				*		
Alhagi graecorum									*		*	
Ceratophyllum demersum	15	5		30	10		5			10	10	20
Chara sp.			5	*	5					5		
Cressa cretica									*	*	*	
Cynanchum acutum									*			
Hydrilla verticillata	5			*						25	5	20
Myriophyllum sp.	10	30	5	5	40							
Najas marina			70		5						10	
Phragmites australis	10	20	5	30	30	30	50	20	40		50	50
Phoenix dactylifera											*	
Potamogeton crispus												
Potamogeton lucens	40	*		20								10
Potamogeton pectinatus	10	10	5	5			5			40		
Potamogeton perfoliatus				*						*		
Salvinia natans						5				*	*	
Schoenoplectus litoralis	*	*	*	5	*						*	
Suaeda sp.						20		5	*			
Tamarix sp.			*			20		20	20			
Typha domingensis	20	30	*	10	5	10	10	5		20	5	*
Vallisneria sp.				*								

*Trace occurrence-detectable.

It is important to underscore that this is a provisional classification system that will be modified in the future as more knowledge of Iraqi habitats is acquired. At this point, it is divided into three major habitat categories: (1) Water, (2) marsh and (3) terrestrial habitat. These three categories include six classes and each one of them is divided into subclasses and, in some cases, secondary subclasses. Table 3 outlines the provisional "Iraqi Marshlands Habitat Classification System" for the marshes of southern Iraq and their associated surrounding terrestrial habitats.

Habitat Types

The proposed "Iraqi Marshlands Habitats Classification System" presented in Table 3 is based on vegetation due to the ecological importance of vegetation communities and because vegetation is a result of the ecological conditions. Table 4 describes the specific habitats seen within the study areas along with a basic site description of example study sites.

Table 3. Provisional "Iraqi Marshlands Habitat Classification System".

WATER

1. Inland running water, river or canal

1.1 Unvegetated rivers and canals

1.2 Submerged river and canal vegetation

1.3 Riparian vegetation

2. Inland standing water

2.1 Pond or lake – Unvegetated standing water

2.2 Unvegetated mudflat – Unvegetated mud, temporarily submerged and subject to water level fluctuations

2.3 Flooded communities – Periodically or occasionally flooded land with phanerogamic communities adapted to aquatic environments that are subjected to water level fluctuations and temporary desiccation (*Cyperus difformis*, *C. michelianus*, *C. laevigatus*)

2.4 Aquatic communities – With aquatic vegetation communities formed by free floating vegetation, rooted submerged vegetation or rooted floating vegetation

2.4.1 Free-floating vegetation — With floating vegetation communities (*Lemna* sp. pl., *Salvinia natans*, *Spirodela polyrhiza*) and *Ceratophyllum demersum* and *Hydrocharis morsus-ranae* communities.

2.4.2 Rooted, submerged vegetation – Rooted submerged communities (*Potamogeton* sp. pl., *Vallisneria spiralis*, *Myriophyllum* sp., *Najas* sp. pl., *Hydrilla verticillata*)

2.4.3 Rooted, floating vegetation – Rooted formations with floating leaves (*Nymphaea* sp. pl., *Nuphar luteum*, *Nymphoides indica*)

2.5 Salt water – – Saline ponds and lakes with phanerogamic communities

MARSH

3. Marsh Vegetation

3.1 Permanent Marsh

3.1.1 Helophytic vegetation

3.1.1.1 Reed bed (*Phragmites australis* beds)

3.1.1.2 Reed mace bed (*Typha domingensis* beds)

3.1.1.3 *Schoenoplectus litoralis* bed

3.1.1.4 *Cladium mariscus* vegetation –*Cladium mariscus* bed

3.1.2 Woody vegetation – Tree size formations with willow (*Salix* sp.) and poplars (*Populus* sp.) within the marsh, excluding riparian treed formations having a linear structure

3.1.2.1 Riparian willow – Dominated by willow formations (*Salix* sp.)

3.1.2.2 Riparian poplar – Dominated by poplar formations (*Populus* sp.)

3.2 Brackish or saltwater marsh vegetation – Brackish or saline marshes with halophytic vegetation

3.2.1 Salt pioneer swards – Pioneer communities growing on salt or brackish mudflat (*Salicornia* sp. pl. community)

TERRESTRIAL HABITATS

4. Desert

4.1 Desert shrub

4.2 Unvegetated desert

4.3 Unvegetated saline lands

5. Woodlands

5.1 Woodland, forest and other wooded area

5.2 Shrub

6. Herbaceous vegetation

6.1 Grassland

6.2 Steppe

6.3 Sparsely vegetated land

Table 4. The habitat classes identified at each site with site description.

Central March CM	Site code	Types of habitat	General description of the site
	HAB-CM-2	2.4.2 Rooted submerged vegetation 3.1.1.1 Helophytic vegetation (reed bed) 3.1.1.2 Helophytic vegetation (reed mace bed) 2.4.1 Free-floating vegetation	This is an open water area that is adjacent to the road on the east and surrounded by reed beds in the other directions; there also are groups of reeds that are distributed randomly inside the area. There are small groups of *Typha* sp. (reed mace beds) and *Schoenoplectus litoralis* close to the road (in the east side of area). The water is shallow. The open area is covered by submerged plants and most of them are decayed at the surface.
	HAB-CM-5	1.1 Unvegetated river and canal 2.4.2 Rooted submerged vegetation 3.1.1.1 Helophytic vegetation (reed beds) 3.1.1.2 Helophytic vegetation (reed mace beds) 2.4.1 Free-floating vegetation	Similar to Site CM-2 (thus an open water area with randomly distributed reed groups). There is a road adjacent to the site from the east and there are small *Typha* groups (on the east side of the area). There are small areas beside the road where submerged vegetation is absent and the water is deeper than the rest of area. The submerged plants are more dense than Site CM-2 but similarly decayed.
	HAB-CM-10	2.4.2 Rooted submerged vegetation 3.1.1.1 Helophytic vegetation (reed beds)	This is Lake is also known as a "Bargah". It is a large open water area with submerged vegetation and surrounded from all directions by reeds (reed beds). There are small groups of reed (known as "Tahala") in the middle of the Bargah. Fishing occurs in the area by nets and electroshock.
	HAB-CM-11	2.4.2 Rooted submerged vegetation 3.1.1.1 Helophytic vegetation (reed beds) 2.4.1 Free-floating vegetation	This is considered as an extension to Abu Sobatt canal, which is an inlet to Al Baghdadia Lake (Bargah). This canal divides the area into two sides (east and west) but the habitats are the same on both sides of the canal. They have small open water areas with a high density of submerged plants and are surrounded by reeds and *Typha* from all directions. All submerged plants are decayed on the surface of water. The canal is bordered by a line of *Typha* followed by a line of reeds on both sides. This is a water buffalo grazing area. There is extensive fishing with nets in the moving water of the canal.
	HAB-CM-12	2.4.2 Rooted submerged vegetation 3.1.1.1 Helophytic vegetation (reed beds) 2.4.1 Free-floating vegetation	This open water area (known locally as "Bargah") has submerged vegetation in different densities. It is surrounded on all sides by reeds beds and there are groups of reeds inside the area of the Bargah. Most of the submerged plants are decayed on the water surface. This area had been burned before and the ground was brownish and included spots with a low density of submerged plants.
	HAB-CM-13	2.3 Amphibious communities 2.4.1 Free-floating vegetation 3.1.1.1 Helophytic vegetation (reed beds) 4.2 Unvegetated desert 6.3 Sparse vegetation	A paved road divides this area into two sides: The west side is an aquatic habitat with reed beds and a water passage close to the road. There is also an area of high ground to the southwest with terrestrial plants (*Tamarix* sp.) and aquatic plants (dry *Phragmites australis*). The soil is wet indicating that this is a seasonal marsh. The east side includes three types of habitat, (a)[c] in the northern portion are reed beds and reed mace beds; (b)in the middle area is dry land without plants that is use by the local people; and (c) in the southern portion is terrestrial vegetation. This area includes high usage by water buffalo, including breeding activity.

Central March CM	**Site code**	**Types of habitat**	**General description of the site**
	HAB-CM-25	3.1.1 Helophytic vegetation (reed beds) 4.1 Desert shrubs 2.4.1 Free-floating vegetation	This is a dry area with a mix of terrestrial plants (to the southwest) and aquatic plants (to the northwest and northeast). There is a small area that still contains some shallow water (5–20 cm depth). The area is considered a seasonal marsh. There is a paved road adjacent to the area on the west. There are many people who live along the road and breed water buffalo. Note: The siting of this area was determined by two coordinates to the west and the description places it about 1 km toward the east.
	HAB-CM-26	5.1 Unvegetated desert 3.1.1 Helophytic vegetation (reed beds) 4.1 desert shrubs	This is a dry area (a seasonal marsh) with *Phragmites* that was dry. It also has terrestrial plants (*Tamarix* sp. *and Suaeda* sp.). There is a paved road to the east of area and as one moves northward, the plant cover decreases and the area becomes more desert-like.
	HAB-CM-27	3.1.1 Helophytic vegetation (reed beds) 4.1 desert shrubs	This is a dry site (seasonally wet) that is located to the west of a soil embankment that extends beside the area from north to south. The entire area is covered by dry reeds with low density intermixed with terrestrial vegetation (*Tamarix* sp. *and Suaeda* sp.).
	HAB-CM-28	2.4.2 Rooted submerged vegetation 3.1.1.2 Helophytic vegetation (reed mace beds) 4.1 desert shrubs 2.4.1 Free-floating vegetation	The main part of this area is open water with rooted submerged vegetation and surrounded by reed mace beds (*Typha domingensis*) from the east and west. From the north there are reed beds. From the south, there is a small canal and road. There are small soil embankments to the southeast of the area. The area is used for water buffalo grazing.
Abu Zirig (AZ)	HAB-AZ-1	1.1 Unvegetated river and canal 2.4.2 Rooted submerged vegetation 3.1.1.1 Helophytic vegetation (reed beds) 2.4.1 Free-floating vegetation	The major habitat here is reed beds and there are small open water areas inside the reed beds. This area is adjacent to the road on the south and to a soil embankment of the river that is adjacent to the area and has openings that feed the marsh with water from the river on the west side of the marsh. There are date palm trees on the soil embankment. This area is considered a water buffalo grazing area; local people cut and collect the reeds for water buffalo feeding and manufacturing of goods. The area is close to Al Fuhood City.
	HAB-AZ-2	1.1 Unvegetated river and canal 2.4.2 Rooted submerged vegetation 3.1.1.1 Helophytic vegetation (reed beds) 2.4.1 Free-floating vegetation	This is a water passage (canal) with a depth of about 2 meters and width of about 25–30 meters, bordered on both sides by reeds that achieve heights of about 2–3 meters above the water surface. The canal extends from north to south. There are areas close to the reeds with dense and decayed submerged plants, and there is a narrow area in the middle of an open, moving water area devoid of plants and deeper than the rest of canal. This area is used for breeding by some birds on the submerged plants (the tops of these plants have emerged above the water surface due to the decreasing water level).

Conclusions and recommendations

The study area and its 12 survey sites in the Central Marsh of Iraq, were set up to assess the application in a real life situation of the Habitat Hectare Assessment (HHA) methodology and to develop a practical classification system for Iraqi habitats based on anticipated habitat classes that had been previously observed. A provisional hierarchical classification system, the "Iraqi Marshlands Habitat Classification System", was created to facilitate mapping these habitats into distinct units. Six habitat classes have been identified, each of which is divided into several subclasses. However, the people of the local communities in these marshes use specific terms to describe habitat types. Two examples are "bargah" which means a pond or lake with unvegetated standing water habitats, and "sibil" which means inland running water/river or canal. Efforts are being made to associate these local names with the scientific categories that have been identified so the classification system and maps becomes practical for local use. This habitat classification system is still undergoing development and will be subjected to further rigorous review.

The author urges consideration of the following recommendations that directly consider plant diversity and the health of the habitats of the southern marshes of Iraq:

It is recommended that additional habitat survey work in other areas in Iraq be initiated in order to verify the applicability of the provisional classification system and its methodology.

In 2008, the Nature Iraq team observed that, in this area, water levels are still decreasing in addition to having on-going poor water quality conditions. To return to a better state comparable to pre-1990 conditions (e.g. before drying of these marshes) for both nature and the local people of the southern marshes of Iraq, it is recommended that Iraq should maximize the restoration of as much of the ecological character of this area as possible.

Application of a standardized habitat classification is essential to monitoring of the progress of this restoration effort. It is recommended that the provisional habitat classification system discussed in this paper be completed and put into operational use as soon as feasible.

The habitat types of greatest importance in restoration efforts will be those that bring stability and economic value to the local communities. The area strongly needs a permanent increase in the quantity of useable water to help restore habitats that are critical to water buffalo for example, a mainstay of the local marsh people. Thus, it is recommended that Iraq make all efforts to foster the restoration of its freshwater sources that once flowed from the Euphrates River and the Tigris River.

Restoration of healthy habitats also requires improvement in water quality. It is further recommended that the Government of Iraq should establish wastewater treatment plants at the points of discharge in the cities that are located on the inlets of these marshes and help to restore the hydrological regime. Increases of water quality and water levels can likely assist in limiting the growth of reeds (such as Phragmites australis) and help restore the ecological character of these marshes.

Finally, it is also recommended that stakeholders initiate training programs to reduce human disturbance and engage the local community in these restoration efforts through education and awareness building about ecosystem health and the importance of particular habitats.

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References

Abdulhassan NA (2007) Preliminary study for the habitats in southern Iraq. Unpublished report. Sulaimani, Kudistan, Iraq: Nature Iraq.

Al-Sa'ady HA, Al-Mayah AA (1983) Aquatic Plants of Iraq. Center for the Arab Gulf. Basrah, Iraq: University of Basrah. (In Arabic).

Davies CE, Moss D, Hill MO (2004) EUNIS Habitat Classification. Copenhagen: European Environmental Agency and European Topic Centre on Nature Protection and Biodiversity. Accessed: http://http://eunis.eea.europa.eu/habitats/jsp.

DSE (Department of Sustainability and Environment) (2004) Vegetation Quality Assessment Manual-Guidelines for Applying the Habitat Hectares Scoring Method. Version 1.3. Melbourne, Australia: Department of Sustainability and Environment, Government of the State of Victoria. Accessed: http://www.dse.vic.gov.au.

FGDC (Federal Geographic Data Committee) (1996) Vegetation Classification and Information Standard. Reston, Virginia, USA: FGDC Secretariat. Cited in Sayre et al. (2000).

Google Image Search (2008) Fall 2008, Accessed: http://www.image.google.com.

Grossman DH, Faber-Langendon D, Weakley AS, Anderson M, Bourgeron P, Craword R, Goodin K, Landaal S, Matzler K, Patterson K, Pyne M, Reid M, Sneddon L (1998) International Classification of Ecological Communities: Terrestrial Vegetation of the United States. Vol. 1. The National Vegetation Classification System: Development, Status, and Application. Arlington, Virginia, USA: The Nature Conservancy. Cited in Sayre et al. (2000).

New Eden Group (2008) Draft Management Plan for the Central Marsh National Park, Iraq. Sulaimani, Kurdistan Iraq. Unpublished.

Rubec CDA (2008) Draft Management Plan for the Hawizeh Marsh Ramsar Site, Iraq. Sulaimani, Kudistan, Iraq: Nature Iraq. Report developed for the Iraq National Marshes and Wetlands Committee. Accessed: www.natureiraq.org.

Sayre R, Roca E, Sedaghatkish G, Young B, Keel S, Roca R, Sheppard S (2000) Nature in Focus. Rapid Ecological Assessment. Washington, D.C., USA: Island Press.

Tiner RT (1999) Wetland Indicators. A Guide to Identification, Delineation, Classification, and Mapping. Boca Raton, Florida, USA: CRC Press.

Townsend CC, Guest E (1966) Flora of Iraq. Vol. 2. University Press, Glasgow, United Kingdom: Robert MacLehose and Company Limited.

Townsend CC, Guest E (1968) Flora of Iraq. Vol. 9. University Press, Glasgow, United Kingdom: Robert MacLehose and Company Limited.

Townsend CC, Guest E (1974) Flora of Iraq (Vol. 3). University Press, Glasgow, United Kingdom: Robert MacLehose and Company Limited.

Townsend CC, Guest E (1980a) Flora of Iraq (Vols. 4-I). University Press, Glasgow United Kingdom: Robert MacLehose and Company Limited.

Townsend CC, Guest E (1980b) Flora of Iraq (Vols. 4-II). University Press, Glasgow, United Kingdom: Robert MacLehose and Company Limited.

Townsend CC, Guest E (1985) Flora of Iraq (Vol. 8). Tonbridge, United Kingdom: The Whitefriars Press Ltd.

Warming E (1909) Oecology of Plants. An Introduction to the Study of Plant Communities. Oxford, United Kingdom: Clarendon Press. (Updated English version of 1896 text). Cited in Tiner (1999).

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RESEARCH ARTICLE

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Morphological, phylogenetic and physiological diversity of cyanobacteria in the hot springs of Zerka Ma'in, Jordan

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Abstract

The freshwater thermal springs of Zerka Ma'in, located in Jordan in the mountains of Moab east of the Dead Sea, are densely inhabited by cyanobacteria up to the highest temperature of 63 °C. We have investigated the cyanobacterial diversity of these springs and their outflow channels by microscopic examination, culture-dependent and culture-independent phylogenetic analysis, and by physiological studies of selected isolates of special interest. Both unicellular and filamentous types of cyanobacteria are present, and we identified morphological types such as *Thermosynechococcus*, *Chroogloeocystis*, *Fischerella* (*Mastigocladus*), *Scytonema* (occurring as large masses at lower temperatures), and others. Although morphologically similar cyanobacteria have been identified in hot springs world-wide, the Zerka Ma'in strains were phylogenetically distinct based on 16S rRNA gene sequence analysis. Considerable diversity was detected also in the gene sequences of *nifH* (nitrogenase reductase), encoding one of the key enzymes involved in nitrogen fixation. Nitrogen fixation in a *Mastigocladus* isolate obtained from the springs was investigated in further depth. The heterocystous strain could fix nitrogen (as assayed by acetylene reduction) at temperatures up to 53 °C.

Keywords

Cyanobacteria, Jordan, Zerka Ma'in, thermophilic cyanobacteria, biodiversity, 16S rRNA phylogeny, nitrogen fixation

Introduction

The hot springs (up to 63 °C) of Zerka Ma'in, located in Jordan in the mountains of Moab near the north-eastern end of the Dead Sea (Fig. 1) were first mentioned by the Jewish-Roman historiographer Flavius Josephus (37 to c. 100 C.E.): "In the ravine which encloses the town [Herod's fortress Machaerus; the present day ruins of Makaur] on the north, there is a place called Baaras. … In this same region flow hot springs, in taste widely differing from each other, some being bitter, while others have no lack of sweetness."

The first explorer to reach the Zerka Ma'in hot springs was the German Ulrich Jasper Seetzen (1767–1811), who visited the site just over 200 years ago. In the report of his visit to the site in 1807 he mentioned the presence of green slimy material that consists of microscopic algae: "These springs are about two hours distant from the Dead Sea, to which the track from here appears to be very difficult. In the water grew a green slimy small alga" (Seetzen 1854; translation A.O.). It is curious that none of the later explorers who visited the site in the course of the 19th century and the first years of the 20th century mentioned the so prominent green growth in the waters of the hot springs (Figs 2A-C). However, a few observations on the microbial mats in the springs were published by the German geologist Max Blanckenhorn, who surveyed the area in 1908: "An algologist could find here, as well as in the other hot sulfur springs of Palestine, a wonderful area for observations and collection. … There where the water was particularly hot, blue-green Cyanophyceae appeared to dominate. For the rest, the whole bottom of the stream and the rocks present in it are covered by green mats. These felt-like mats are often small in the form of a sponge or pillow with a dark-green, somewhat wrinkled skin …" (Blanckenhorn 1912; translation A.O.).

The cyanobacterial flora of the nearby hot springs of the Zara area near the shore of the Dead Sea, the site of the ancient Kallirrhoë (Donner 1963), was surveyed in 1936 (Frémy and Rayss 1938; Rayss 1944). However, no studies of the cyanobacteria of Zerka Ma'in have been conducted until 2005. The peace treaty between Jordan and

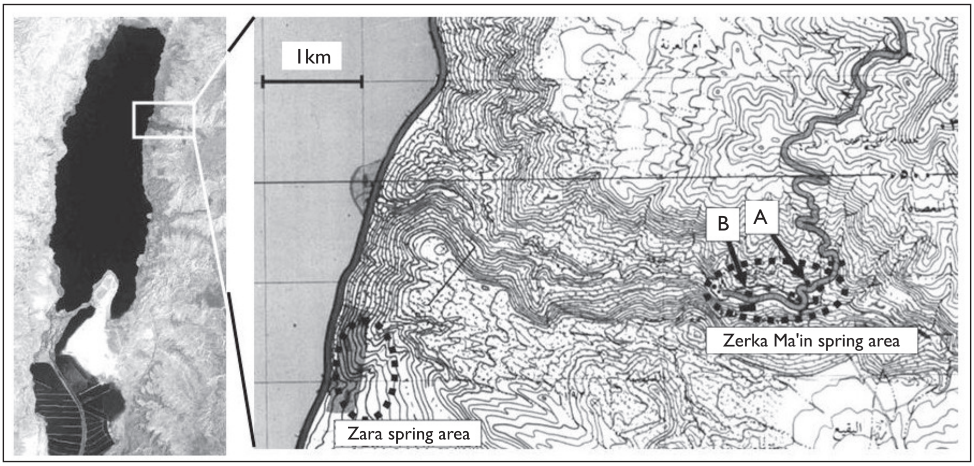

Figure 1. Satellite image of the Dead Sea and the location of the Zerka Ma'in spring area.

Israel of 1994, and the establishment of the Bridging the Rift Foundation in the year 2000, promoting peace in the Middle East through science, enabled us to perform the first biological surveys to characterize the highly interesting microbial communities of Zerka Ma'in and to discover some of its many interesting and sometimes unique features. Sponsored by the Bridging the Rift Foundation, our team of Jordanian and Israeli scientists has made a number of sampling trips to the site in 2005 to 2007 (Ionescu et al. 2007, 2009; Oren et al. 2008). We here present some of the results of our cyanobacterial diversity studies of the Zerka Ma'in hot springs, based both on microscopical characterization of the organisms present and on molecular, 16S rRNA gene-based techniques.

Materials and methods

Sample collection, cyanobacterial cultivation and identification

Cyanobacterial mats were collected from the Zerka Ma'in springs on December 14, 2005, November 16, 2006 and July 3, 2007. Samples were transferred to glass vials

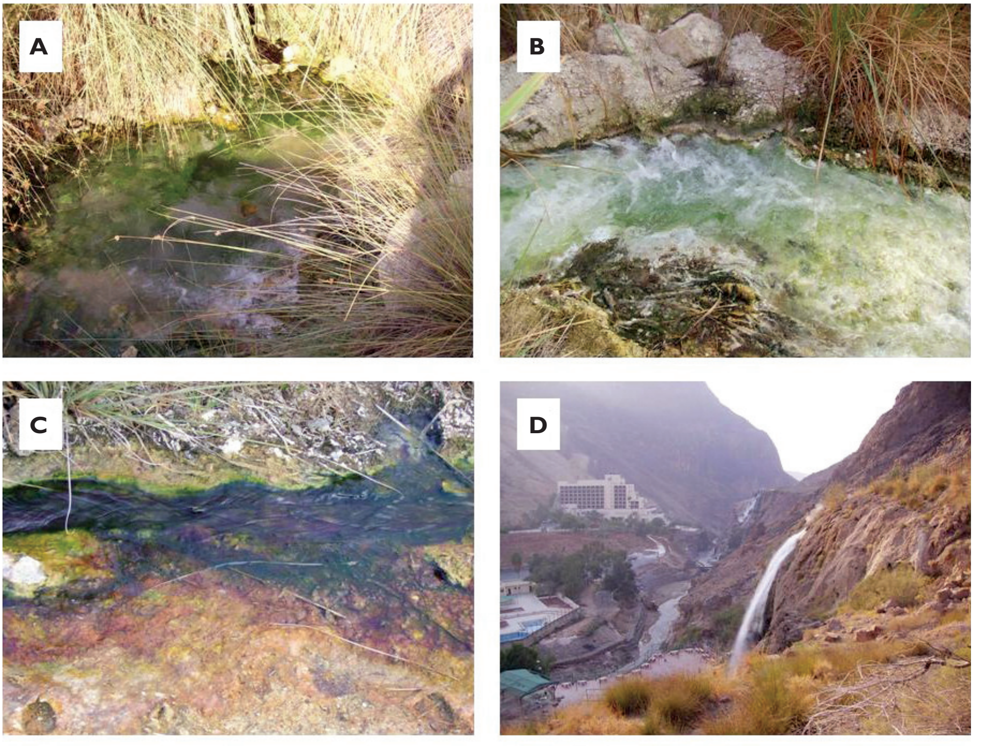

Figure 2. Views of the thermal spring area of Zerka Ma'in. Panel A shows one of the springs in Area A indicated in Fig. 1, Panel D provides an overview of the waterfalls with hot water of about 58 °C to 60 °C in Area B.

and tubes and used for microscopic identification of the organisms present, isolation of cyanobacterial strains, and molecular studies. Most experimental work referred to below was done based on the July 2007 samples. Site A (Figs 1, 2A) consists of two pools, the upper one flowing into a lower one through a pipe. The temperature of the upper one was 63 ºC during all sampling trips. The lower pool ranged between 62 ºC and 63 ºC. The upper pool is shallow (ca 50 cm) and surrounded by rock walls. Green mats were found on the rocks, at and slightly above the water air interface. Submerged rocks are covered by mats as well. The lower pool is deeper, larger and surrounded by vegetation. Site B (Fig. 1B) is located ca 500 m west of site A. Green mats are found on the channels' earth banks and on submerged rocks. An orange mat is often found beneath the green mat. Site C (Fig. 1C) is a stream located 25 m above site A. The main stream is a combination of two smaller ones at a temperature of 25 °C and 51 °C. Over a distance of 25 m from the confluence point the temperature of the stream reaches 39 °C. The water from the springs at site B flows through a 50 m channel that ends in a waterfall (Fig. 1D). The temperature of the water was 59 °C along the entire channel.

Samples were examined and photographed in a Zeiss Axiovert 135 TV microscope equipped with phase-contrast optics. Morphological types were identified to the genus level on the basis of the identification systems proposed by Geitler (1932) and the "form-genus" approach of Castenholz (2001). When relevant, names in common use but without standing in the botanical and bacteriological nomenclature were used as well (e.g. *Thermosynechococcus*). We have isolated representative types of filamentous and unicellular cyanobacteria by enrichment and direct isolation on agar plates of growth medium BG-11, using incubation temperatures of 45 °C and 55 °C. Cultures are maintained on agar slides in the laboratory of A.O.; the filamentous *Mastigocladus*-like strain nBTRCC 101 has been submitted for deposition in the UTEX - The culture collection of algae at the University of Texas at Austin (temporary accession number: ZZ867).

Sequencing and analysis of cyanobacterial 16S rRNA genes

For molecular 16S rRNA-sequence based analysis, samples were placed in 15 ml sterile tubes containing 2 ml of lysis buffer (100 mM Tris-HCl, 50 mM EDTA, 10 mM NaCl, 1% SDS, pH 8), followed by extraction with phenol-chloroform-isoamyl alcohol (25:24:1). After washing the extracts with chloroform-isoamyl alcohol (24:1), DNA was precipitated with cold ethanol, washed with ice-cold 70% ethanol, and resuspended in water. Fragments of the 16S rRNA gene were amplified by PCR, using cyanobacteria-specific primers as specified in Ionescu et al. (2009). The primer sets 29F – 809R and 740F – 1494R were used for cultures, while 106f and 781R (Nübel et al. 1997; Ionescu et al. 2009) were used for environmental samples. Amplicons originating from environmental sequences were cloned using the InsTAclone kit (K1214, Fermentas, Lithuania) and verified using colony PCR. Successful reactions were sent for cloning and sequencing at the Genome Sequencing Center at Washington University, St. Louis, MO. To obtain reliable results each clone was sequenced in both directions. Each individual sequence used for the phylogenetic analysis is the result of two aligned sequences from the same clone. All sequences were compared to the NCBI nr databases using the NetBlast application (available from NCBI). The top five hits as well as some additional relevant sequences were used for phylogenetic analysis. Sequences were aligned using the Muscle 3.6 software (Edgar 2004). Phylogenetic trees were constructed using the MEGA 4.0 (Tamura et al. 2007). The Distance Matrix was calculated using the Jukes-Cantor algorithm and the trees were constructed using the Minimum Evolution method. Validity of tree topology was evaluated using the bootstrap method (100 replicates). Environmental 16S rRNA gene sequences from Zerka Ma'in are available from the GenBank at accession numbers EU326950-327016.

Nitrogen fixation studies

To assess the importance of nitrogen fixation to the cyanobacteria in the Zerka Ma'in springs, we used the acetylene reduction test to quantify the nitrogenase activity of the community. Biomass was collected from the major spring of Area A (63 °C) and from two nearby streams with temperatures of 51 °C and 39 °C. Acetylene reduction tests were performed *in situ* in the light and in the dark for 1:45–2:45 hours, incubation times being limited due to logistic constraints. Full details of the experimental conditions were given by Ionescu et al. (2009).

Results

Physical and chemical properties of the samples collected

The major springs that issue at sites A and B as indicated in Fig. 1 had a temperature of 62 °C to 63 °C, independent of the season of sampling. Most samples collected from the springs and their outflow channels had temperatures between 63 and 51 °C. During our last sampling trip (June 2007) we found a channel located about 100 m north of the major springs of site A, which had not been surveyed previously. Its water temperature was 39 °C.

The waters of the springs differed little in chemical properties. The total dissolved salts concentrations ranged between 1,267 and 1,445 mg/L, with an alkalinity of 110–130 mg/L. A typical analysis (water from site A pictured in Fig. 2A) gave (mg/L): Cl^-, 810; SO_4^{2-}, 196; Ca^{2+}, 186; Mg^{2+}, 91; Na^+, 86; K^+, 35. Up to 0.3 mM sulfide was measured in the water sampled near the sources. The pH ranged from 6.4 to 6.8. More detailed chemical analyses have been reported elsewhere (Abu Ajamieh 1980, 1989; Rimawi and Salameh 1988; Ionescu et al. 2009).

Microscopical observations of the spring samples and the cyanobacterial cultures obtained

Microscopical examination of samples collected from the springs and their outflow channels showed a dominance of unicellular cyanobacteria. Figure 3 presents a representative selection of organisms encountered at temperatures between 58 °C and 63 °C. At the highest temperatures the cyanobacterial mats were dark green in colour (Figs 2A, B). Here unicellular *Thermosynechococcus*-type cyanobacteria dominated (Fig. 3A). As water temperature decreases downstream the outflow channels, additional types of cyanobacteria started to appear, as shown in Figs 3B and 3C. Occasionally tightly wound, thin *Spirulina*-like filaments were encountered (Oren et al. 2008). Thus far phylogenetic analyses of environmental samples (see below) did not yield any *Spirulina*-like 16S rRNA gene sequences; however, some of our clones clustered with *Limnothrix*, a genus that includes a (non-thermophilic) spiral organism (*Limnothrix chlorospira*).

The area of the outflow channels in Area B above the waterfalls (Fig. 2D) had mats coloured in part orange, and here we mainly found small *Gloeocapsa*-like unicellular cyanobacteria. More extensive illustrations of the morphological types of cyanobacteria found in the Zerka Ma'in spring area were published elsewhere (Ionescu et al. 2009).

Of special interest is the profuse growth of masses of the branching heterocystous cyanobacterium *Scytonema* observed along some of the outflow channels in the spring area above the waterfalls. The *Scytonema* colonies consist of blackish to dark-green material attached to the rocks (Fig. 4). The colonies are not in direct contact with the hot spring waters, but they are continuously sprayed by small droplets of water from the stream.

We succeeded in growing *Chroogloeocystis* and *Mastigocladus*/*Fischerella* types from samples collected at different places of the Zerka Ma'in thermal area. Some of the iso-

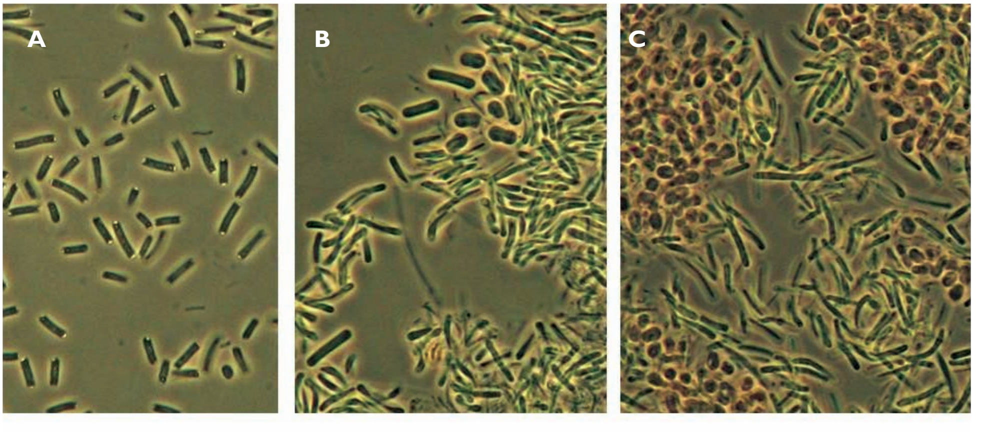

Figure 3. Microphotographs of unicellular cyanobacteria from the Zerka Ma'in hot springs. Different types of unicellular cyanobacteria are shown, collected from the Zerka Ma'in hot springs in November 2006 at temperatures between 58 °C and 63 °C.

lated strains resembled morphologies seen in the field-collected material; others were of types not observed by direct examination of the samples (Ionescu et al. 2007, 2009). The cultures are referred to by accession numbers that start with tBTRCCn (see also Fig. 5). Unfortunately we did not yet succeed in obtaining *Thermosynechococcus*-like organisms from the Zerka Ma'in springs in culture.

16S rRNA gene-based phylogenetic diversity of cyanobacteria

Figure 5 presents the phylogenetic relationships of selected environmental 16S rRNA gene sequences obtained from the Zerka Ma'in springs, indicating the temperature from which the different sequences were recovered, and the sequences of the cyanobacteria grown from the springs as indicated by their tBTRCCn numbers. Only part of the sequences obtained is shown, and similar related sequences are clustered together. For example, the upper box in Fig. 5 ("*Thermosynechococcus*-like clones") is based on 46 distinct and different sequences amplified from the environmental DNA. The *Thermosynechococcus* cluster appears to be particularly diverse in the springs (Oren et al. 2008; Ionescu et al. 2009). More extensive phylogenetic trees were given in Oren et al. (2008).

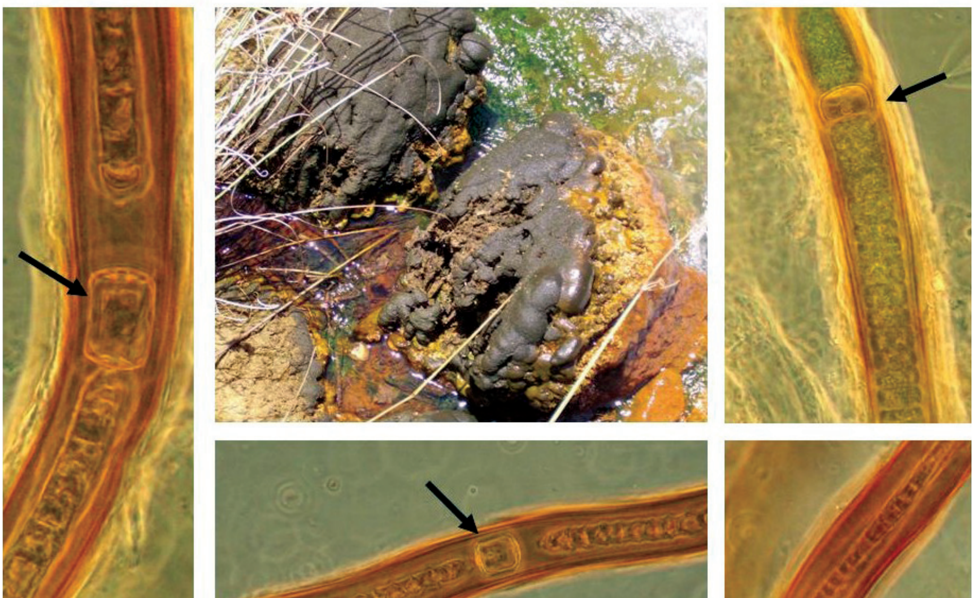

Figure 4. Growth of *Scytonema* in the Zerka Ma'in area. The picture shows growth of large colonies of *Scytonema* on rocks sprayed by water from a thermal stream, and microphotographs of *Scytonema* filaments showing the thick sheath and heterocysts (arrows).

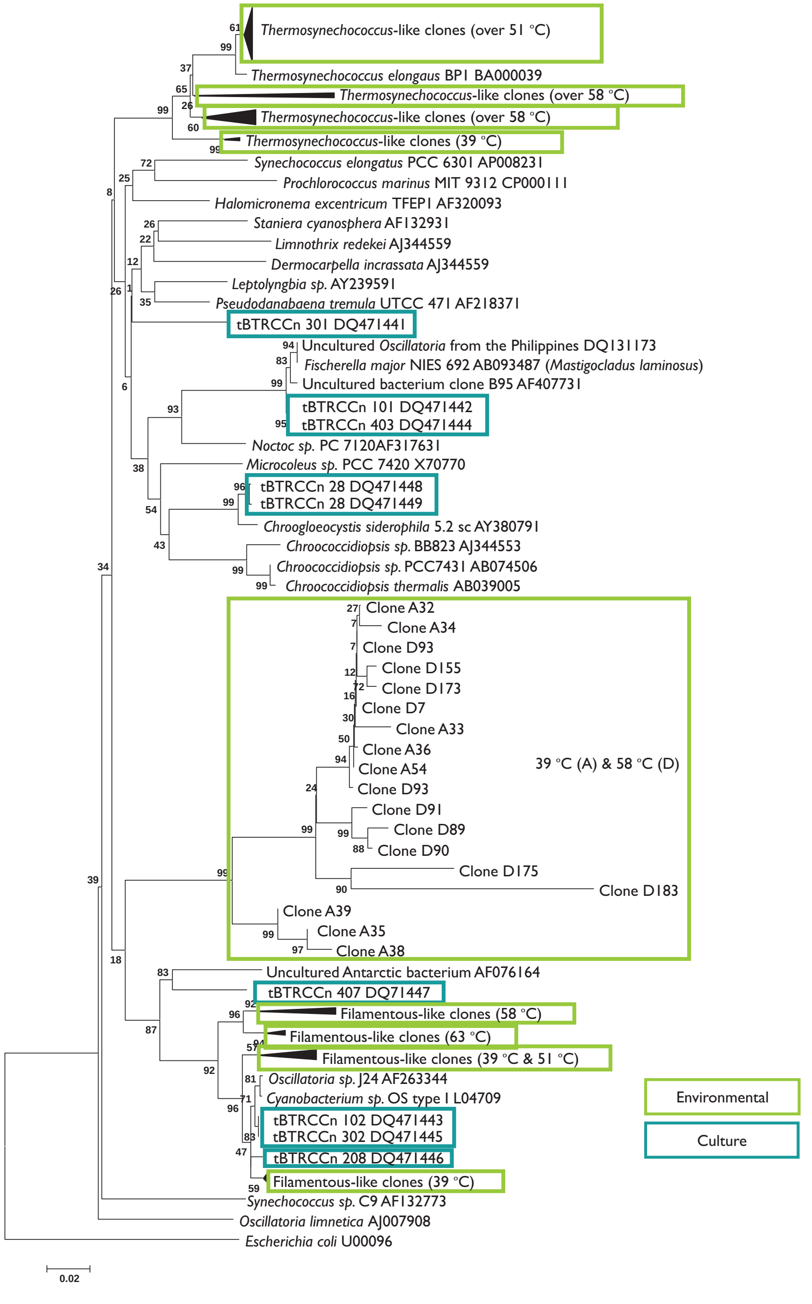

Figure 5. Phylogenetic tree of Zerka Ma'in cyanobacteria, based on 16S rRNA gene sequences. The minimum evolution phylogenetic tree is based on 16S rRNA gene sequences of cyanobacterial isolates obtained from the Zerka Ma'in springs (indicated by tBTRCCn numbers) and on cyanobacterial sequences recovered by PCR amplification from DNA extracted from biomass collected between December 2005 and June 2007 from the thermal springs and outflow channels. The temperature of the waters from which the 16S rRNA genes were recovered is indicated.

Nitrogen fixation studies on the thermophilic cyanobacteria

Chemical analyses of the Zerka Ma'in spring waters (Abu Ajamieh 1980, 1989) show that the concentrations of nitrogen compounds (ammonium, nitrate) are negligible. Therefore the ability to fix gaseous nitrogen will be advantageous to the cyanobacteria that colonise the springs. The observation of heterocysts in the *Scytonema* colonies bordering some of the outflow channels (Fig. 4) suggests that nitrogen fixation by the local cyanobacterial communities may indeed occur.

We detected significant rates of acetylene reduction at all sites sampled, including the 63 °C site. The highest calculated nitrogenase activity (0.0025–0.012 nmol N µg chlorophyll^{-1} h^{-1}) was obtained at 51 °C in the dark. At 63 °C we measured rates of 0.001–0.0025 nmol N µg chlorophyll^{-1} h^{-1}, rates that are low, but significantly higher than background values. Acetylene reduction rates in the light were 30% to 50% lower than those measured in the dark.

The fact that light inhibited nitrogenase activity suggests that the activity is probably located in oxygenic phototrophs, the nitrogenase of which is inhibited by photosynthetically produced oxygen. To test whether mRNA transcripts of the *nifH* (nitrogenase reductase) gene may be present in the Zerka Ma'in cyanobacterial community at the highest *in situ* temperature of 63 °C, we fixed samples in liquid nitrogen; prepared cDNA from the RNA isolated from the community, and amplified gene sequences using *nifH*-specific PCR primers from this cDNA. Using this procedure we isolated a gene identical to a *nifH* gene found in a filamentous cyanobacterial culture obtained from the site. A full account of these experiments was given by Ionescu et al. (2009).

Gene sequences of cyanobacterial *nifH* genes were recovered both from the community DNA and from selected isolates obtained from the spring. Sequences of *nifH* obtained from the environmental DNA were related to those from *Fischerella*, *Phormidium*, and *Lyngbya* spp. (Ionescu et al. 2009). We also sequenced the *nifH* gene of a heterocystous isolate related to *Mastigocladus*/*Fischerella* (strain nBTRCC 101).

Nitrogen fixation by this isolate is now being investigated in further depth. Optimal rates of acetylene reduction were measured at 45 °C (up to 24.5 nmol N µg chlorophyll^{-1} day^{-1}). The maximum temperature for nitrogen fixation in this strain was found to be 52 °C to 53 °C. When grown under light/dark cycles, acetylene reduction rates were higher than under constant light. When a culture grown in nitrate-rich medium was transferred to nitrogen-depleted medium, formation of heterocysts was induced, and acetylene reduction activity started after 48 hours. Quantitative PCR analysis showed expression of the *nifH* gene to be subject to a circadian rhythm. The nature of the phenomenon is currently under investigation.

Discussion

At the highest temperatures (up to 63 °C), unicellular cyanobacteria dominated in the Zerka Ma'in springs area. As water temperature decreases downstream the outflow channels, additional types of cyanobacteria started to appear, including filamentous cyanobacteria belonging to the *Mastigocladus-Fischerella* group, known from thermal springs worldwide (Brock 1978; Castenholz 1969, 1973; Ward and Castenholz 2000). *Spirulina labyrinthiformis* was earlier reported as the dominant organism in material collected by A. Aaronson from a 52 °C spring of Zerka Ma'in (Rayss 1944). Aaronson had joined Blanckenhorn during his above-mentioned 1908 survey of the area (Blanckenhorn 1912), but no further information is available on the exact site and date of collection and no further details have been reported.

The profuse growth of masses of the branching heterocystous cyanobacterium *Scytonema* observed along some of the outflow channels in the spring area above the waterfalls (Fig. 4) is of special interest. It is well possible that these are the "felt-like mats …. in the form of a sponge or pillow with a dark-green, somewhat wrinkled skin", to which Blanckenhorn referred in the quotation given above. Growth of *Scytonema* was also reported from the nearby hot springs of Zara that were surveyed for cyanobacteria and microalgae in 1936 (Frémy and Rayss 1938). The filaments of *Scytonema* are surrounded by a thick, dark brown, layered sheath that has a high content of scytonemin, a dimeric indole alkaloid synthesised from aromatic amino acid residues, which absorbs UV-A radiation (Castenholz and Garcia-Pichel 2000). Qualitative and quantitative information about the content of sctyonemin and other UV-absorbing pigments in the material from Zerka Ma'in has been provided elsewhere (Oren et al. 2008). Scytonemin has its absorbance maximum at 384 nm, with a broad absorption band. Thus the cells are effectively protected against UV-induced cell damage. It remains to be determined, to what extent this property is of importance to the physiology of *Scytonema* at the Zerka Ma'in site. At its location at about 250 m below mean sea level the local level of UV radiation is lower than at higher altitudes, and hardly any traces of other UV-absorbing compounds such as mycosporine-like amino acids could be detected in any other types of cyanobacteria found so abundantly in and around the springs (Oren et al. 2008). Literature data also suggest that the scytonemin content of cyanobacteria that produce the compound may be regulated by factors not directly connected with the light intensity and light quality found in their environment (Castenholz and Garcia-Pichel 2000). It should be noted that *Scytonema* is not a thermophile, and at Zerka Ma'in its colonies are exposed to ambient air temperatures rather than to the temperatures of the thermal spring water (Fig. 4). Surveys of springs in Yellowstone National Park, USA (where UV levels are high at an elevation of > 2000 m above sea level) showed 55 °C to be the upper limit for growth of sheathed, scytonemin-containing species of cyanobacteria such as *Pleurocapsa* and *Calothrix* (Wickstrom and Castenholz 1978).

The isolation of a unicellular cyanobacterium with a 16S rRNA gene with 99% similarity with *Chroogloeocystis siderophila*, an organism originally found in iron-rich thermal environments in Yellowstone and requiring high iron concentrations for growth (Brown et al. 2005), is remarkable. The Zerka Ma'in waters do not have a high iron content.

Based on the information presented in the tree shown in Fig. 5, a number of interesting conclusions can be drawn: (1) All sequences recovered from the cyanobacteria of Zerka Ma'in appear to be unique, and none of the sequences found was identical to any sequence found in the GenBank database. (2) Some of the Zerka Ma'in organisms have close relatives in other thermal springs worldwide, but there are other types as well that have not been reported from elsewhere. (3) None of the sequences found in our cultures were retrieved directly from the environmental DNA as well. This holds also true for the two cultures of heterocystous cyanobacteria affiliated with the genera *Fischerella* and *Mastigocladus* we have obtained and studied for their nitrogen fixation properties (see below). No related sequences were yet detected among the environmental 16S rRNA gene fragments cloned from the DNA isolated from the site. (4) In many cases sequences found in the lower temperature waters show phylotypes distinct from those present at the higher temperature sites. (5) The sequences in the large box (A32 to A38), which appear to have no equivalent elsewhere, are of special interest. We have no cultured representative of this group yet, so no information is available about the morphology of the organisms that harbor these sequences. Sequences belonging to this group have been retrieved both from 58 °C thermal waters and from a cooler site where we measured 39 °C.

Chemical analyses of the Zerka Ma'in spring waters (Abu Ajamieh 1980, 1989) show that the concentrations of nitrogen compounds (ammonium, nitrate) are negligible. Therefore studies of the nitrogen fixation potential of the cyanobacterial community in the springs were initiated. The finding of nitrogenase at 63 °C was somewhat surprising, as a temperature of 55 °C was generally considered to be the upper limit of nitrogen fixation by cyanobacteria (*Mastigocladus*) in hot spring environments (Fogg 1952, Stewart 1970, Wickstrom 1980). However, the recent finding of transcripts of *nif* genes derived from *Synechococcus* ecotypes in Octopus Spring, Yellowstone National Park, USA, at temperatures up to 63.4 °C (Steunou et al. 2006) suggests that the upper temperature limit of cyanobacterial nitrogen fixation may be higher than previously assumed.

It is intriguing that the unique environment of the Zerka Ma'in hot springs has not been surveyed before by biologists. To our knowledge this is the only site in the Middle East where thermal waters of such high temperatures flow undisturbed and enable the development of a diverse community of phototrophic and other microorganisms adapted to life at temperatures up to 63 °C. The hot springs of Tiberias, Israel, used as a thermal spa since Roman times, reach temperatures very similar to those of Zerka Ma'in. Some exploration of the cyanobacteria present at the site has been done in the past (Dor 1967). However, these springs do not currently flow freely outdoors, so that thermophilic cyanobacteria and other microorganisms adapted to life at high temperatures have little opportunity to develop.

Conclusions

The thermal springs of Zerka Ma'in, Jordan, are inhabited by a great diversity of thermophilic unicellular and filamentous cyanobacteria including *Thermosynechococcus*, *Chroogloeocystis*, *Fischerella* (*Mastigocladus*), and *Scytonema* (occurring as large masses at lower temperatures). Based on 16S rRNA gene sequence analysis, the Zerka Ma'in strains were phylogenetically distinct from morphologically similar cyanobacteria found in hot springs world-wide. Low rates of nitrogen fixation were detected up to 63 °C, the highest temperature recorded in the springs.

Acknowledgements

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References

Abu Ajamieh M (1980) The geothermal resources of Zerqa Ma'in and Zara. The Hashemite Kingdom of Jordan, Geological Survey and Bureau of Mines, Natural Resources Authority, Amman. 82 pp.

Abu Ajamieh M (1989) Mineral resources of Jordan. The Hashemite Kingdom of Jordan, Ministry of Energy and Mineral Resources, Natural Resources Authority, Amman. 147 pp.

Blanckenhorn M (1912) Naturwissenschaftliche Studien am Toten Meer und im Jordanthal. Bericht über eine im Jahre 1908 (im Auftrage S.M. des Sultans der Türkei Abdul Hamid II. und mit Unterstützung der Berliner Jagor-Stiftung) unternommene Forschungsreise in Palästina. R. Friedländer & Sohn, Berlin. 478 pp.

Brock TD (1978) Thermophilic microorganisms and life at high temperatures. Springer-Verlag, New York, 465 pp.

Brown II, Mummey D, Cooksey KE (2005) A novel cyanobacterium exhibiting an elevated tolerance for iron. *FEMS Microbiology Ecology* 52: 307–314.

Castenholz RW (1969) Thermophilic blue-green algae and the thermal environment. *Bacteriological Reviews* 33: 476–504.

Castenholz RW (1973) Ecology of blue-green algae in hot springs. In Carr NG, Whitton BA (eds) *The biology of blue-green algae.* Blackwell Scientific Publications, Oxford, 379–414.

Castenholz RW (2001) General characteristics of the Cyanobacteria. In Boone DR, Castenholz RW (eds.) *Bergey's manual of systematic bacteriology,* 2nd ed., vol. 1. Springer, New York, 474–487.

Castenholz RW, Garcia-Pichel F (2000) Cyanobacterial responses to UV-radiation. In Whitton BA, Potts M (eds) *The ecology of cyanobacteria. Their diversity in time and space.* Kluwer Academic Publishers, Dordrecht, 591–611.

Donner H (1963) Kallirrhoë. Das Sanatorium Herodes' des Großen. *Zeitschrift des deutschen Palästinavereins* 79: 59–89.

Dor I (1967) Algues des sources thermales de Tibériade. *Sea Fisheries Reseach Station, Haifa Bulletin* 48: 3–29.

Edgar RC (2004) MUSCLE: multiple sequence alignment with high accuracy and high throughput. *Nucleic Acids Research* 32: 1792–1797.

Fogg GE (1952) Studies on nitrogen fixation by blue-green algae II. Nitrogen fixation by *Mastigocladus laminosus* Cohn. *Journal of Experimental Botany* 2: 117–120.

Frémy P, Rayss T (1938) Algues des sources thermales de Kallirrhoe (Transjordanie). *Palestine Journal of Botany Jerusalem Series* 1: 27–34.

Geitler L (1932) Cyanophyceae. In Dr. L. Rabenhorst's Kryptogamen-Flora von Deutschland, Österreich und der Schweiz, vol. XIV. Akademische Verlag, Leipzig; reprint (1985): Koeltz Scientific Books, Koenigstein. 1196 pp.

Ionescu D, Oren A, Hindiyeh MY, Malkawi HI (2007) The thermophilic cyanobacteria of the Zerka Ma'in thermal springs in Jordan. In Seckbach J (Ed) *Algae in extreme environments.* Springer, Dordrecht, 413–424.

Ionescu D, Oren A, Levitan O, Hindiyeh M, Malkawi H, Berman-Frank I (2009) The cyanobacterial community of the Zerka Ma'in hot springs, Jordan: morphological and molecular diversity and nitrogen fixation. *Algological Studies* 130: 17–26.

Josephus. The Jewish war – Books IV – VII. Translated by Thackeray H St J. (1979). Harvard University Press, Cambridge, MA. 687 pp.

Nübel U, Garcia-Pichel F, Muyzer G (1997) PCR primers to amplify 16S rRNA genes from cyanobacteria. *Applied and Environmental Microbiology* 63: 3327–3332.

Oren A, Ionescu D, Hindiyeh M, Malkawi H (2008) Microalgae and cyanobacteria of the Dead Sea and its surrounding springs. *Israel Journal of Plant Sciences* 56: 1–13.

Rayss T (1944) Materiaux pour la flore algologique de la Palestine I. Les Cyanophycées. *Palestine Journal of Botany Jerusalem Series* 3: 94–113.

Rimawi O, Salameh E. (1988) Hydrochemistry and groundwater system of the Zerka Ma'in-Zara thermal field, Jordan. *Journal of Hydrology* 98: 147–163.

Seetzen UJ (1854) Ulrich Jasper Seetzen's Reisen durch Syrien, Palästina, Phönicien, die Transjordan-Länder, Arabia Petraea und Unter-Aegypten. Kruse F (Ed). 2nd Band. G. Reimer, Berlin. 400 pp.

Steunou A-S, Bhaya D, Bateson MM, Melendrez MC, Ward DM, Brecht E, Peters JW, Kühl M, Grossman AR (2006) *In situ* analysis of nitrogen fixation and metabolic switching in unicellular thermophilic cyanobacteria inhabiting hot spring microbial mats. *Proceedings of the National Academy of Sciences of the USA* 103: 2398–2403.

Stewart WDP (1970) Nitrogen fixation by blue-green algae in Yellowstone thermal areas. *Phycologia* 9: 261–268.

Tamura K, Dudley J, Nei M, Kumar S (2007) MEGA4: Molecular Evolutionary Genetics Analysis (MEGA) software version 4.0. *Molecular Biology and Evolution* 24: 1596–1599.

Ward DM, Castenholz RW (2000) Cyanobacteria in geothermal habitats. In Whitton BA, Potts M (Eds) *The ecology of cyanobacteria. Their diversity in time and space.* Kluwer Academic Publishers, Dordrecht, 37–59.

Wickstrom CE (1980) Distribution and physiological determinants of blue-green algal nitrogen fixation along a thermogradient. *Journal of Phycology* 16: 436–443.

Wickstrom CE, Castenholz RW (1978) Association of *Pleurocapsa* and *Calothrix* (Cyanophyta) in a thermal stream. *Journal of Phycology* 14: 84–88.

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RESEARCH ARTICLE

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Space-time variability of phytoplankton structure and diversity in the north-western part of the Arabian Gulf (Kuwait's waters)

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Abstract

Studies of the phytoplankton community were conducted in the north-western Arabian Gulf in 2005 and 2006. Seven stations throughout Kuwait's waters were sampled. The influence of nutrient-rich freshwaters from the Shatt al-Arab resulted in high phytoplankton productivity characterized by high species diversity with a strong dominance of diatoms, especially in northern Kuwait. Phytoplankton species richness gradually increased from north to south. Spatial distribution of both total abundance and biomass of phytoplankton indicated significant differences in species structure and size spectrum of the microalgae. The analysis of the temporal and spatial phytoplankton variability (distribution of total abundance and biomass, similarity of species compositions and local community structure) indicated that Kuwait's northern waters differed from areas further south in terms of phytoplankton structure and temporal and spatial variability. Environmental heterogeneity is mainly attributed to the influence of the Shatt al-Arab system, which affects the temporal and spatial variability of the phytoplankton community.

Keywords

Phytoplankton; diversity, Arabian (Persian) Gulf, Kuwait

Introduction

The ecology of phytoplankton in the Arabian Gulf has been studied during the last few decades and is relatively well known (e.g. Al-Kaisi 1976, Jacob et al. 1979, Subba Rao et al. 1999, Al-Yamani et al. 2004). Long-term studies of temporal and spatial distributions and the effects of physical effects on the phytoplankton community in Kuwait's waters have not been reported.

The main freshwater inflow into the northern Arabian Gulf is from the Shatt al-Arab River. Seasonal freshwater supply from the Shatt al-Arab has local effects on the Gulf's marine environment, especially on Kuwait's waters. The phytoplankton community in the Arabian Gulf is heterogeneous, with species compositions differing among localities (Al-Yamani et al. 2004). The main objective of this study was to describe the spatial and temporal variability of phytoplankton diversity, species composition and abundance in Kuwaiti territorial waters.

Methods

Daytime phytoplankton surveys in Kuwaiti waters were conducted twice a month from October 2005 through September 2006 at seven stations (Fig. 1).

One-liter samples from the surface layer (1 m depth) were collected by 5–liter Niskin bottles and preserved with acidified Lugol solution. After full sedimentation during at least four weeks, the top water volume was carefully siphoned off without disturbing the precipitated algae (using rubber a hose with curved end). The Utermöhl sedimentation method was used for quantitative analysis of the Niskin bottle samples (Utermöhl 1958). The concentrated sample was well shaken and an aliquot of 25 ml from each sample was placed in the standard Utermöhl settling counting chamber. After sedimentation during a 24 h period in a well-covered dark desiccator, the area of the settling chamber was examined with a Leica DMIL inverted microscope at ×200 to ×400 magnifications. For phytoplankton enumeration, the appropriate area of the chamber was scanned, depending on the abundance of each species. Randomly-selected viewing fields were examined for very abundant phytoplankton species, whereas the complete chamber area was scanned for less abundant species. The abundance for each phytoplankton taxon was calculated as the number of cells per liter. In total, 76 Niskin bottle samples were examined.

The SeaBird SBE-19 CTD profiler equipped with a Seapoint turbidity meter was deployed at each station to obtain *in-situ* data for salinity (psu), temperature (°C) and turbidity (NTU) distribution. Water samples for measuring inorganic nutrients concentrations were collected by a 5-liter Niskin bottle from one meter depth and filtered using Whatman GF/C filters. The automated determination for nitrate and silicate was based on Strickland and Parsons (1972), using a Skalar SUN Flow Analyser. For ammonia concentrations, we employed the phenol-hypochlorite method and added the required reagents immediately after obtaining the water sample. Ammonia concentra-

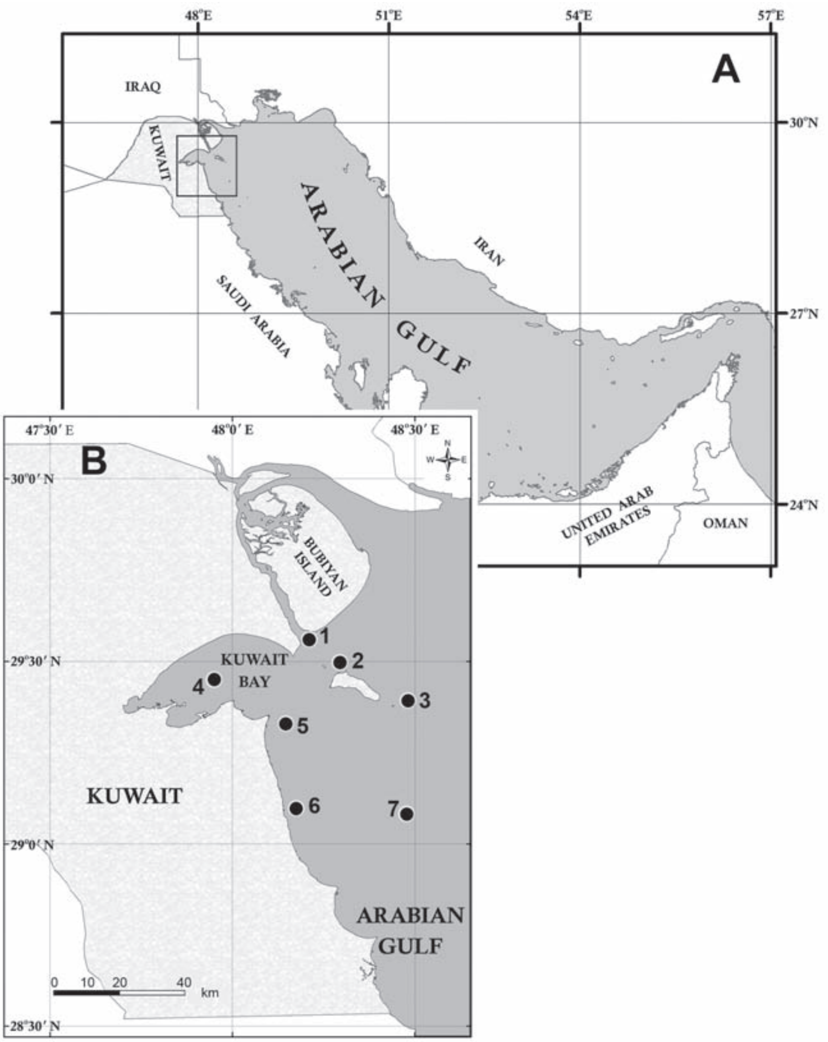

Figure 1. Area of investigation. **A** Arabian Gulf, with inset showing the greater region in which the sampling area was located **B** Map of Kuwait showing locations of the stations sampled for phytoplankton in 2005 and 2006 (black dots).

tions were measured in the laboratory using a Beckman DU-650 spectrophotometer after 24 hours of incubation in the dark (Grasshoff et al. 1983).

In order to estimate phytoplankton biomass, the individual volumes of cells (μm3) and biomass as wet weight (mg/L) for each species were calculated according to approximate geometrical fi gures (Hillebrandt et al. 1999). To describe phytoplankton diversity, the Margalef's richness index, Shannon's heterogeneity index and Pielou's evenness index were used. Similarity between species compositions was calculated by Jaccard and Czekanowski-Sørenesen indices of association. Cluster analysis was applied to generate dendrograms (group average method), based on the Jaccard and

Bray-Curtis distance matrixes among samples. Pearson correlation coefficients were calculated for estimations of the relationships between environmental variables and the phytoplankton community. Calculation of indices and cluster analysis were performed using Primer 6.1.9 software (Primer-E Ltd.).

Results

Phytoplankton diversity

The phytoplankton community in Kuwaiti waters in 2005 and 2006 was very diverse with 200 taxa identified, representing nine classes (Table 1). Diatoms (Bacillariophyceae) exhibited the greatest diversity with 134 taxa identified, followed by dinoflagellates (Dinophyceae, 56 taxa); Cyanophyceae, Prymnesiophyceae and Dictyochophyceae, each with two taxa, and Cryptophyceae, Prasinophyceae, Euglenophyceae and Ebriidae represented by a single taxon.

Diatoms and dinoflagellates were the most diverse groups. Centric and pennate diatoms accounted for the highest diversity with 84 and 50 taxa, respectively. Among the centric diatoms, the most diverse genera were *Chaetoceros* (22 taxa), *Rhizosolenia* (12 taxa) and *Coscinodiscus* (nine taxa). For pennate diatoms, the *Nitzschia* group was represented by 17 taxa (14 species of the genus *Nitzschia* and three species of the morphologically close genera *Pseudo-nitzschia* and *Cylindrotheca*). The genus *Pleurosigma* was represented by seven species. Of the 56 species of dinoflagellates, over one-half were represented by three genera: *Protoperidinium* (16 taxa), *Ceratium* (eight taxa) and *Prorocentrum* (five taxa).

As a whole, a pronounced prevalence of diatoms was typical for the phytoplankton community in Kuwaiti waters throughout the year. On the average, diatoms contributed 70% to the total species diversity. Their prevalence was at a maximum (80% to

Table 1. Diversity of the main phytoplankton groups recorded from Kuwaiti waters in 2005 and 2006; phytoplankton groups presented here follow the classification scheme of Throndsen (1997), which was partially modified by Christensen (1962, 1966).

Class	Diversity (number of taxa)
Cyanophyceae	2
Cryptophyceae	1
Dinophyceae	56
Prymnesiophyceae	2
Dictyochophyceae	2
Bacillariophyceae	134
Prasinophyceae	1
Euglenophyceae	1
Ebriidea	1
Total phytoplankton diversity	200

100%) during the autumn-winter period, especially in November and December, and reduced during the spring and summer (April to July), especially at stations 5, 6 and 7. Dinoflagellates contributed only 22% to the total species diversity, with a maximum of 40% to 70% during the spring-summer period, and <10% (often <1%) at stations 1 and 2 throughout the study period, probably a result of reduced salinities in the Shatt al-Arab discharge.

Variability of phytoplankton concentrations

Microalgae abundance ranged from 3.06×10^3 to 1.24×10^7 cells/L (1.88 ± 2.59×10^5 cells/L on average) and biomass from 0.03 to 161 mg/L (9.96 ± 24.10 mg/L on average). Diatoms dominated phytoplankton abundance numerically as well as in biomass, accounting for 99% of the latter depending on season. Phytoplankton concentrations, which were obtained in this study, are within the range of those reported previously (Al-Yamani at al. 2004, 2006).

Space-time variability of the phytoplankton structure

Assessments of the spatial and temporal variability of the structure of the phytoplankton community studied are presented in Table 2. High levels of average paired similarity between both the species compositions within stations (0.703) and within year (0.710) as well as small dispersion of these parameters testify a rather high taxonomic homogeneity of the phytoplankton community in Kuwaiti waters and similar trends in seasonal development of phytoplankton at different locations.

For the community as a whole, the high β-diversity value (21.5) indicates heterogeneity in species compositions among the replicates. Average similarity of species structure within samples (average paired samples similarity using the Czekanowski-Sørensen Index) was 0.390 ± 0.141.

Temporal variability of phytoplankton

Analysis of seasonal variability within the phytoplankton community was performed using the hierarchical clustering using the Jaccard Index of similarity. For the samples collected throughout the year, we identified four different periods based on sample similarities (Fig. 2A). The community structure of samples within each period showed a higher degree of similarity than that of samples between periods. Cluster analysis found seasonal differences as follows: Cluster-1, late winter-spring (January, February and March); Cluster-2, spring (April and May); Cluster-3, summer-early autumn (July and September) and Cluster-4, late autumn-winter (October, November, and December). Each cluster was identified by distinct phytoplankton associations (Fig. 2B, Table 3).

Table 2. Space-time variability of the phytoplankton community structure.

Attributes of community structure	Spatial variability (7 stations)	Temporal variability (10 months)
Mean number of species per sample	126	104
Number of species with absolute occurrence	40	36
Number of samples containing all species	0	0
Occurrence Index (β-diversity)	63.32	52.26
Czekanowski-Sørensen Index	0.703 ± 0.149	0.710 ± 0.058

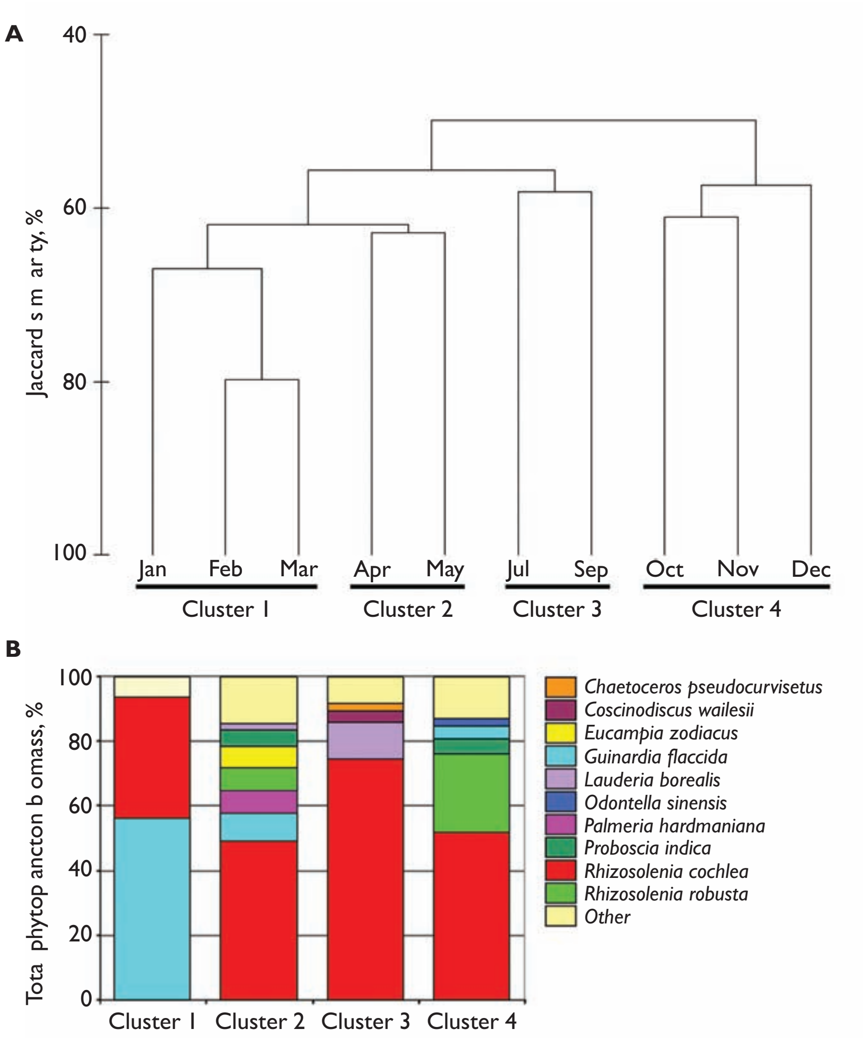

Figure 2. Temporal variability of the phytoplankton community. **A** the dendrogram of cluster analysis (group average method), based on Jaccard's distance matrix among samples (10 months × 200 species; monthly average biomass values) **B** compositions of dominant species for different phytoplankton associations within each period isolated by cluster analysis.

Table 3. Phytoplankton concentrations and community structure within different periods of the year, which were isolated by cluster analysis. Cluster numbers correspond to those in Fig. 2A.

Cluster	Total phytoplankton biomass, mg/L (mean ± SD)	Species richness		Species diversity	Community evenness
		Species number	Margalef's index	Shannon's index	Pielou's index
Cluster-1	18.5 ± 16.9	118	11.91	1.05	0.22
Cluster-2	2.2 ± 0.8	105	13.53	2.09	0.45
Cluster-3	17.0 ± 12.1	129	13.14	1.11	0.23
Cluster-4	7.5 ± 9.0	179	19.95	1.75	0.34

Composition of the top-dominant species and their percentage contributions to the total phytoplankton biomass from each isolated period of the year are shown in Fig. 2B. The beginning of the year (Cluster-1) was characterized by dominance of large-sized diatoms *Guinardia flaccida* (53% of the total phytoplankton biomass) and *Rhizosolenia cochlea* (39%). Late winter phytoplankton development was characterized by minimal values of species diversity and community evenness and maximum concentrations of phytoplankton. Diversity among dominant species during the spring (Cluster-2) was higher due to the appearance of large- and medium-sized diatoms: *Palmeria hardmaniana*, *Rhizosolenia robusta*, *Eucampia zodiacus*, *Proboscia indica* and *Lauderia borealis*. In the spring season, the decline of *G. flaccida* resulted in *R. cochlea* becoming the dominant species. This period was characterized by minimum phytoplankton concentrations; but species diversity and community evenness increased to their highest levels. In summer-early autumn (Cluster-3), the phytoplankton community consisted mainly of *R. cochlea* complemented by significant concentrations of *L. borealis*. The rather high levels of phytoplankton biomass during the late autumn-winter period (Cluster-4) were supported mainly by *R. cochlea* and *R. robusta* populations. The maximum values of phytoplankton species richness were found in October to December. Generally, winter months of 2005/2006 were characterized by the main bloom of phytoplankton biomass in the surface waters (up to 60–80 mg/L in some locations), which started in the northern part of Kuwait in December, moving southward through Kuwait Bay during January and February.

Spatial variability of phytoplankton

To estimate the spatial variability within the phytoplankton community, we applied the Bray-Curtis Similarity Index among stations. Cluster analysis identified three different phytoplankton associations in Kuwaiti waters (Fig. 3).

The first area outlined (Cluster-1, station 1) was located in Kuwait's extreme northern waters closed to the Shatt al-Arab. The second area outlined (Cluster-2) consisted mainly of stations along Kuwait's coast (stations 4, 5 and 6) and included station 2. The remaining area (Cluster-3) was restricted to open waters (stations 3 and 7;

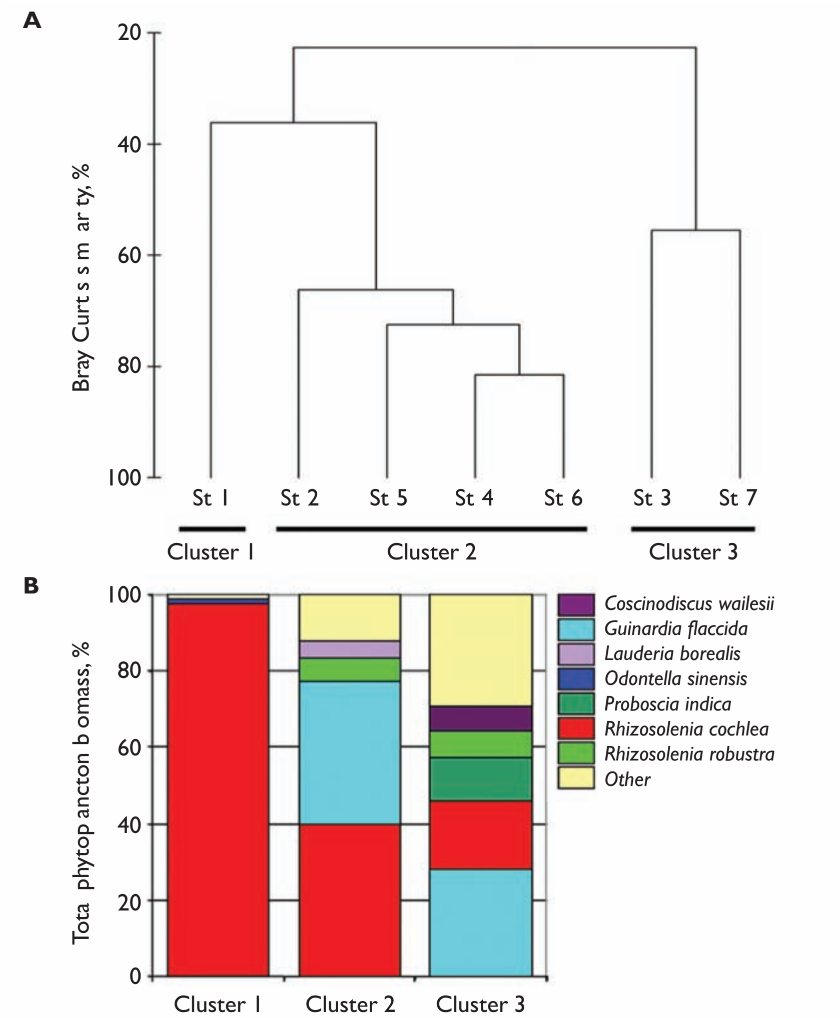

Figure 3. Spatial variability of phytoplankton community. **A** Dendrogram of the cluster analysis (group average method), based on the Bray-Curtis distance matrix among samples (seven stations × 200 species; annual average biomass values) **B** Compositions of dominant species in different phytoplankton associations within each area outlined by the cluster analysis.

Fig. 3A). Within each area outlined, distinct phytoplankton associations were found with regard to composition, concentration, species richness and diversity as well as community evenness. Dissimilarity of community structure between phytoplankton from different associations is illustrated in Fig. 3B and Table 4.

The first association (Cluster-1) greatly differed from other locations by the highest phytoplankton concentrations, the minimum values of species richness, diversity and community evenness. The high levels of phytoplankton biomass were supported

Table 4. Phytoplankton concentrations and community structure within different areas of Kuwait's waters, which were isolated by cluster analysis. The cluster numbers correspond to those in Fig. 3A.

Cluster	Total phytoplankton biomass, mg/L (mean ± SD)	Species richness		Species diversity	Community evenness
		Species number	Margalef's index	Shannon's index	Pielou's index
Cluster-1	15.0	65	6.66	0.16	0.04
Cluster-2	12.1 ± 4.1	176	16.22	1.70	0.33
Cluster-3	2.3 ± 0.8	175	20.66	2.72	0.53

by almost total prevalence of the large-sized diatom *R. cochlea*. Coastal waters were characterized by the dominance of *R. cochlea* and *G. flaccida* (the second association, Cluster-2). Phytoplankton composition in open waters (the third association, Cluster-3) differed clearly from those of northern Kuwait and the coastal waters due to low densities, despite maximum species richness, diversity and community evenness. In decreasing order of abundance for the offshore stations, the most important species included: *G. flaccida*, *R. cochlea*, *Proboscia indica*, *R. robusta* and *Coscinodiscus wailesii*.

Variability of phytoplankton structure along latitudinal gradient

In order to assess macro-scale spatial variability of the phytoplankton community within Kuwaiti waters, we analyzed distributions of species richness and diversity of large taxonomic groups as well as phytoplankton composition along a latitudinal gradient. Figure 4 shows the phytoplankton species richness plotted against latitude. Margalef's index gradually increased from north to south. This trend conformed to a linear regression model, which described 91% of the spatial variability for mean species richness (r^2=0.91). Phytoplankton composition from northern waters near the Shatt al-Arab estuary was less diverse than that of southern waters. The observed increasing trend was supported mainly by an increase of dinoflagellate diversity.

Phytoplankton composition within the northern waters was characterized by high prevalence of diatoms (from 76% to 96% of total species richness; Fig. 5A). If not totally absent, dinoflagellates contributed only 6% to 18% to the total species richness. The portion of dinoflagellates in the phytoplankton increased exponentially along the north-south gradient (Fig. 5B). The diatom/dinoflagellate ratio was equal to 11 within northern waters (station 1); whereas it was reduced to 2.6 in coastal waters, and even further to 2.3 in open waters (115 diatom species versus 50 dinoflagellates).

Relationship between phytoplankton community and environmental variables

In order to detect the differences between various areas within Kuwait's waters, we analyzed the composition of the main environmental factors (salinity, turbidity and nutri-

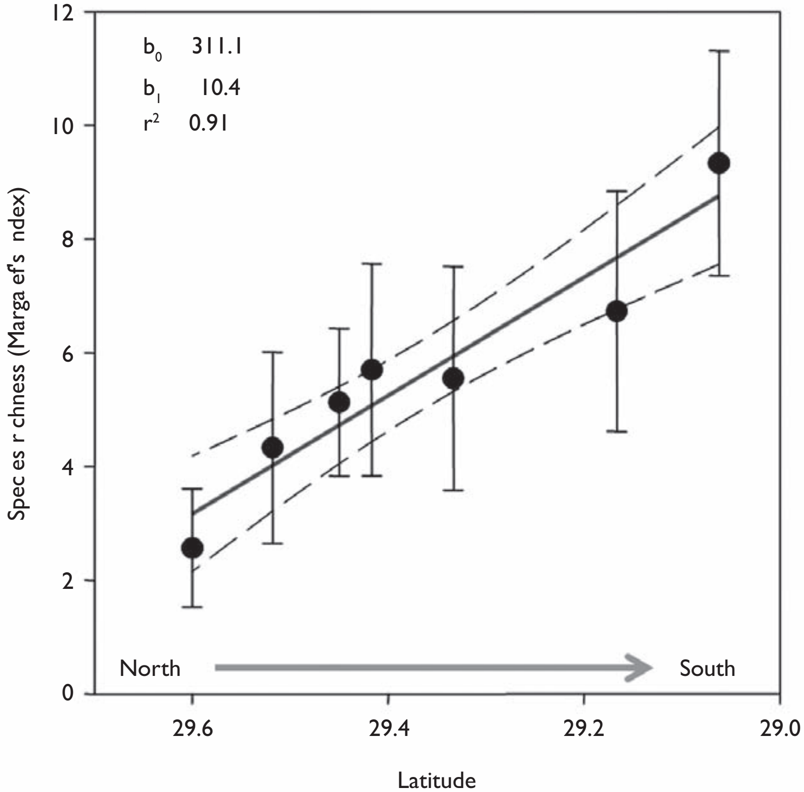

Figure 4. Change of species richness in the phytoplankton community along a north-south latitudinal gradient. The dots represent the annual average values of Margalef's Index ± SD; the solid line represents the linear regression; the dashed lines represent the 95% confidence interval.

ent concentrations). Salinity values increased from the north to the south (Fig. 6A), whereas the opposite trend was observed for turbidity and nutrient concentrations along the latitudinal gradient (Figs 6B–D).

To estimate the relationships between the phytoplankton community and the main environmental variables, we calculated the Pearson correlation coefficients. Correlation analysis was applied to the matrix of annual average values for each variable analyzed (Table 5).

The relationships between phytoplankton and environmental variables were not significant in terms of microalgae concentrations. Correlation analysis, however, revealed strong statistically significant correlations among phytoplankton structure and environmental variables. Species richness of phytoplankton community and selected taxonomical groups as well as percentage contribution of dinoflagellates to the community were strongly correlated with salinity (positive correlations with values of 0.82–0.97, $p < 0.001$), turbidity (negative correlations, r from -0.88 to -0.97) and with

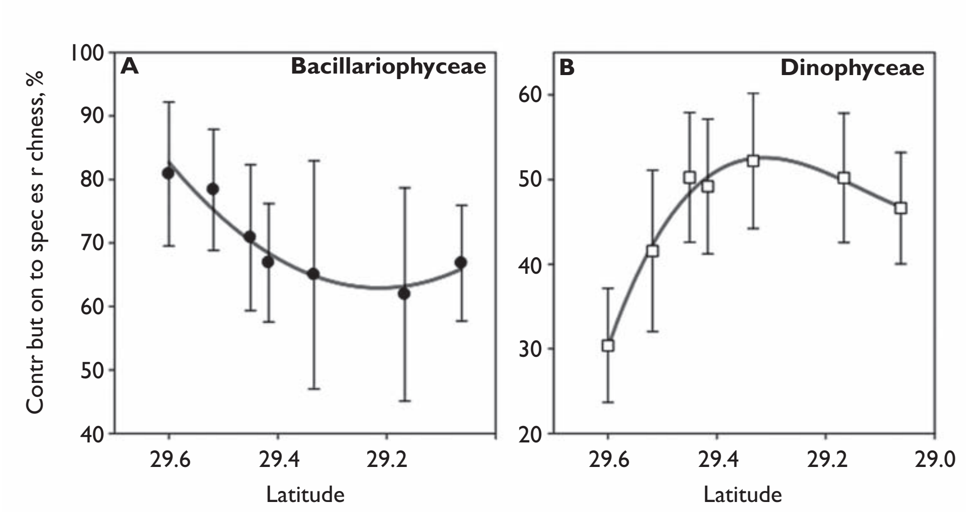

Figure 5. Percentage contribution of phytoplankton groups to the total species richness plotted against latitude. **A** Diatoms **B** dinoflagellates; annual average values of species richness (number of species) ± SD.

nutrient concentrations, especially with silicate (negative correlations, *r* from -0.91 to -0.99) (Table 5). For diatoms, we found significant positive correlations with turbidity as well as with nutrient concentrations. Additionally, the high prevalence of diatoms in phytoplankton composition was associated with low salinity (*r* = -0.98).

Discussion

The relatively small geographic area of Kuwait's waters covers a very important transitional zone at the extreme north-western corner of the Arabian Gulf. From north to south, coastal waters of Kuwait extend for 170 km. There is a range of interaction between the Shatt al-Arab River discharge and the Arabian Gulf marine environment. The shallow waters of Kuwait are characterized by high biological productivity (Al-Yamani et al. 2004), which are supported mainly by very abundant and diverse phytoplankton communities.

The high species diversity of the phytoplankton community (200 identified taxa) is mainly due to diatom algae. The assessment of phytoplankton species diversity presented here is close to the maximum number of phytoplankton taxa recorded in the Arabian Gulf area, which is 223 taxa, including 134 diatoms and 86 dinoflagellates (Jacob and Al-Muzaini 1990). The latest estimation of diversity in Kuwaiti waters was 220 taxa, including 162 diatoms and 53 dinoflagellates (Al-Yamani et al. 2004).

The phytoplankton community in Kuwaiti waters differs from the rest of the Arabian Gulf by high prevalence of diatoms and low dinoflagellate species diversity due to the abundance of silicate nutrients in these waters. The occurrence of a significant

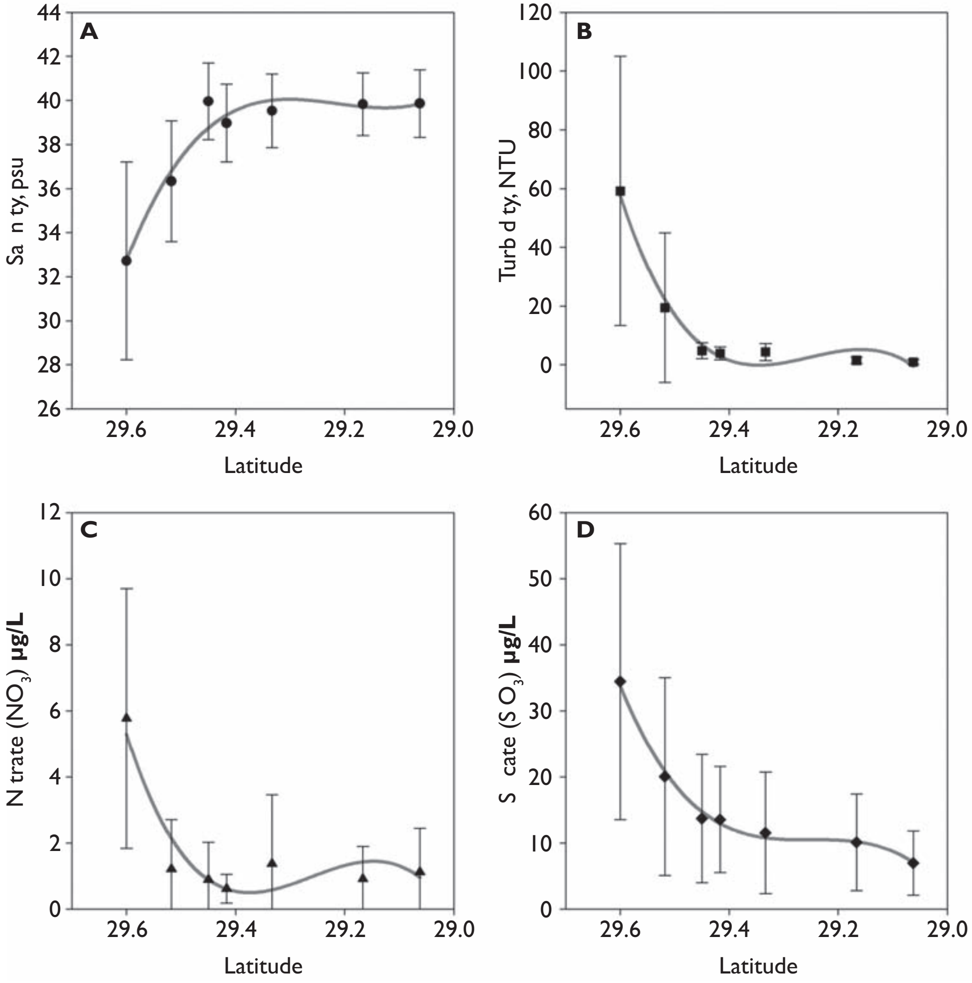

Figure 6. Distribution of environmental variables (annual average values ± SD) along the north-south latitudinal gradient. **A** Salinity **B** turbidity **C** nitrate **D** silicate.

abundance of pennate diatoms, especially benthic taxa (large- and small-sized) diatom algae from periphyton, epipelon and epipsammon associations (genera *Pleurosigma*, *Diploneis*, *Surirella*, *Trachyneis*, *Nitzschia*, *Entomoneis*, *Plagiotropis*) is also noteworthy. For some of them (such as *Pleurosigma* spp., *Surirella fastuosa*, *Trachyneis antillarum,* and *Nitzschia* spp.) significant abundances were observed in some inshore locations.

Both the spatial and temporal components contributed to the variability of the phytoplankton community in Kuwaiti waters. During the winter months, the northern area was characterized by the highest concentrations of phytoplankton, whereas the lowest phytoplankton concentrations were observed in open waters in summer. The minimum diversity level was associated with the spring months, whereas the maximum was in autumn (October). Phytoplankton species richness gradually increased

Table 5. Pearson's Correlation Coefficients (*r*) among phytoplankton community and environmental variables measured in Kuwaiti waters in 2005/2006. The values in bold represent significant correlations ($p < 0.001$).

		Species richness			Species composition	
	Total phytoplankton biomass	**Total phytoplankton**	**Diatoms**	**Dinoflagellates**	**Diatoms contribution**	**Dinoflagellates contribution**
Salinity	-0.62	**0.90**	**0.82**	**0.94**	**-0.98**	**0.97**
Turbidity	0.58	**-0.92**	**-0.88**	**-0.93**	**0.96**	**-0.97**
Ammonia	0.56	**-0.92**	**-0.89**	**-0.92**	**0.93**	**-0.94**
Nitrate	0.46	**-0.85**	**-0.86**	**-0.82**	**0.85**	**-0.88**
Silicate	0.63	**-0.97**	**-0.91**	**-0.99**	**0.98**	**-0.97**

southward, with the lowest richness recorded in the waters closest to the Shatt al-Arab and the highest towards the southern waters.

The analysis of space-time phytoplankton variability allowed the clustering of similar samples and hence the identification of the different phytoplankton associations in Kuwaiti waters. The northern zone is unique and differs from the rest of the study area, which is clearly expressed in the distinctive features of phytoplankton structure and space-time variability. Pronounced differences in the northern area are explained by the strong influence of lower-salinity waters that are discharged from Shatt al-Arab River and the Shatt al-Basrah channel.

The Shatt al-Arab system, which collects the waters of the Tigris, Euphrates and Karun rivers, is the principal fluvial input to the Arabian Gulf, especially to the northern areas including Kuwaiti waters (Al-Yamani et al. 2004). Seasonal freshwater supply from the Shatt al-Arab appears to have a local effect on the marine environment of the examined area. The influence of the Shatt al-Arab River discharge on the northern Arabian Gulf results in a gradient of environmental conditions, which change according to river flow volume. As a result of this interaction, different locations and distinct periods may be identified in Kuwaiti waters. There is a northern zone, which is constantly more dynamic, turbid and rich in nutrients and at the same time less saline. For the other areas of Kuwait's waters, two different time periods were identified: the beginning of the year to May was characterized by higher nutrient concentrations and a decrease in salinity, which corresponds to higher river discharge, while the remainder of the year is characterized by lower nutrient concentrations and higher salinities.

There is a significant correlation among phytoplankton structure and physicochemical variables of Kuwaiti waters. The results suggest that salinity, turbidity and inorganic nutrient concentrations (inorganic nitrogen and silicate) were the main factors controlling changes in the phytoplankton community within the area examined.

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References

Al-Kaisi KA (1976) On the phytoplankton of the Arabian Gulf. 2nd Joint Oceanographic Assembly, Edinburgh, Scotland, 13–24 September 1976. Rome: FAO, 125.

Al-Yamani F, Bishop J, Ramadhan E, Al-Husaini M, Al-Ghadban AN (2004) Oceanographic atlas of Kuwait's waters. Kuwait: Kuwait Institute for Scientific Research. 203 pp.

Al-Yamani F, Subba Rao DV, Mharzi A, Ismail W, Al-Rifaie K (2006) Primary production off Kuwait, an arid zone environment, Arabian Gulf. International Journal of Oceans and Oceanography 1(1):67–85.

Christensen T (1962) Alger. In Böcher TW, Lange M, Sørenson T (eds) Botanik. 2. Systematisk Botanik. Copenhagen: Munksgaard, 1–178.

Christensen T (1966) Alger. In Böcher TW, Lange M, Sørenson T (eds) Botanik. 2. Systematisk Botanik. 2nd edn. Copenhagen: Munksgaard, 1–180.

Hillebrandt H, Durselen C-D, Kirschtel D, Pollingher U, Zohary T (1999) Biovolume calculation for pelagic and benthic microalgae. Journal of Phycology 35: 403–424.

Grasshoff K, Ehrhardt M, Kreming K (Eds.) (1983) Methods of seawater analysis. 2nd edition. Basel: Verlag Chemie. 420 pp.

Jacob PG, Zarba MA, Anderlini V (1979) Hydrography, chlorophyll and plankton of the Kuwaiti coastal waters. Indian Journal of Marine Sciences 8: 150–154.

Jacob PG, Al-Muzaini MA (1990) Marine plants of the Arabian Gulf: a literature review. Kuwait Institute for Scientific research, Report KISR3426. 214 pp.

Strickland JDH, Parsons TR (1972) A practical handbook of seawater analysis. 2nd edition. Bulletin of the Fisheries Research Board of Canada 167: 310 pp.

Subba Rao DV, Al-Yamani F, Lennox A, Pan Y, Al-Said T (1999) Biomass and production characteristics of the first red-tide noticed in Kuwait Bay, Arabian Gulf. Journal of Plankton Research 22: 805–810.

Throndsen J (1997) The planktonic marine flagellates. In Tomas CR (Ed.) Identifying Marine Phytoplankton. San Diego: Academic Press, 591–710.

Utermöhl H (1958) Zur Vervollkommnung der quantitativen Phytoplankton-Methodik. Mitteilungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie 9: 1–38.

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RESEARCH ARTICLE

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Biodiversity of free-living flagellates in Kuwait's intertidal sediments

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Abstract
Taxonomic data of free-living benthic flagellates in Kuwait's intertidal sediments are summarized. A full list of the species composition is presented, including distribution on different sediment types, species occurrence and light micrographs for each taxon identified. A total of 67 flagellate species were identified, representing six classes. Most of them are reported from Kuwait for the first time. The most abundant and diverse species were sand-dwelling dinoflagellates (43 taxa).

Keywords
Benthic flagellates, intertidal sediments, Kuwait

Introduction

The marine coast of Kuwait, which extends for about 170 km, is composed of a variety of coastal habitats (Al-Yamani et al. 2004). Kuwait's coast may conveniently be divided into two primary regions, which reflect the position of Kuwait's offshore energy zones. In the north, suspended material from the Shatt al-Arab delta has settled to form extensive intertidal mud and sand flats within the rather protected low-energy zone of Kuwait Bay. Intertidal sediments grade from mud in the north and west of the Bay, where limited salt marshes may occur, to medium or fine sand beaches at the entrance of the Bay. On the more exposed open coast south of Kuwait Bay in high-energy areas, medium and coarse sand beaches extend down to the Saudi Arabian border and beyond. Within these two broad categories, however, there are several other shoreline types, which can grade into one another. Thus, all stages of mud, sandy mud, muddy sand, sand, sandy-rocky flats, or rocky shore can be found along the coastline of Kuwait, often in close proximity of each other (Jones 1986a, b).

This unique and very productive component of Kuwait's marine ecosystem is poorly studied in terms of its microbenthic community. Previous investigations of marine protists in some parts of Kuwait's coastline focused on their general productivity and/or diversity especially for the diatom/cyanobacteria component of the microalgal community (e.g. Hendey 1970, Clayton 1986, Jones 1986b, Hoffman 1996, Al-Yamani et al. 2004, Al-Zaidan et al. 2006), whereas information on taxonomy and ecology of benthic flagellates in Kuwait's coastal zone is totally lacking. Many of the benthic flagellates are abundant in intertidal substrata and their contributions to benthic and shallow marine ecosystems may be significant. Several species from the benthic flagellated community are known to be potentially toxic; therefore, the study of their biology and potential toxic reactions in shallow waters is important.

The aim of this study was to document the biodiversity of benthic flagellates along the Kuwaiti coastline. Additionally, their abundance and distribution on different sediment types are reported.

Methods

We selected 14 localities along Kuwait's coast (Fig. 1) for our investigation. Each study site stretched for about 100 m and consisted of one or more of the following substrates: mud, sandy mud, muddy sand, or sand. In total, we collected 127 sediment samples from different intertidal heights during 2005 to 2007. Using plastic tube corers, we sampled the top 3 to 4 cm of sandy sediment, or 3 to 4 mm of muddy sediment. These samples were transported to the laboratory where flagellates were separated from the sediment using Uhlig's (1964) frozen seawater method and a 110 µm mesh filter. Flagellates were collected in a Petri dish beneath the filter and examined alive with a Leica DMIL inverted microscope at ×35 to ×200 magnification. For detailed observations, flagellates were isolated by micropipette and examined with a Leica DMLM microscope or with a Carl Zeiss Axiovert 200M microscope using transmitted-light with a bright field and phase contrast at ×400 to ×1000 magnification. Flagellate plate patterns were made using Calcofluor White M2R (Fritz and Triemer 1985). The cells were examined on an epifluorescent (violate excitation ca 430 nm, blue emission ca 490 nm) Axiovert 200M microscope. We examined both the dorsal and ventral sides of each flagellate, and obtained micrographs using either Axiovert 200M microscope equipped with an AxioCam HRc digital camera or a Leica DMLM microscope with a Leica DFC 320 digital camera. Cell size was measured by light microscopy using a calibrated ocular micrometer, and some morphometric measurements were obtained from micrographs using Carl Zeiss Axio Visiton 3.0

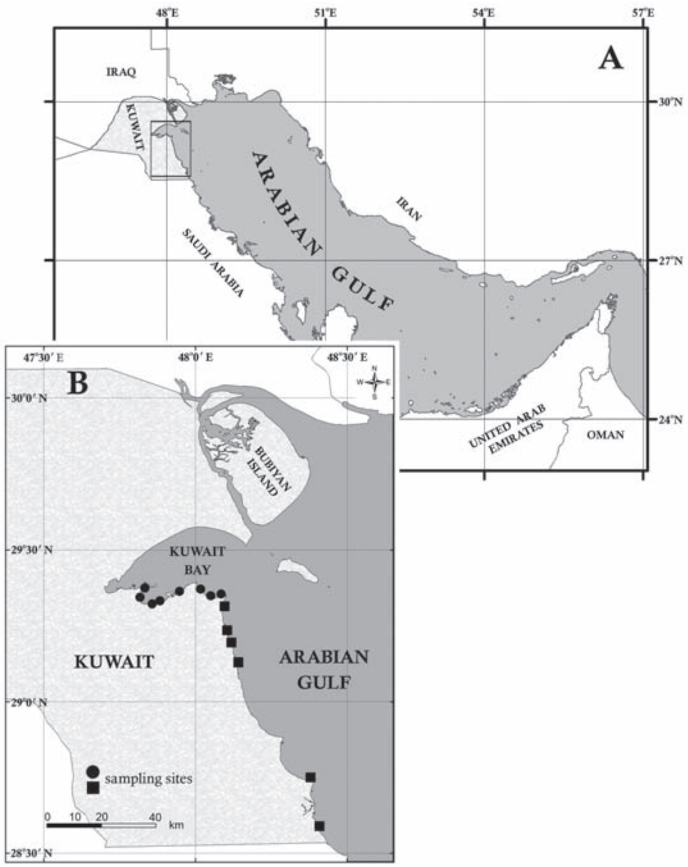

Figure 1. Area of investigation. **A** Arabian Gulf, with inset showing the greater region in which the sampling area was located **B** Map of Kuwait showing sampling sites (sites located within low-energy and high-energy zones are labeled with black dots and black squares, respectively).

software. All observations presented here are based on light microscope investigations of freshly-collected living cells.

We used the taxonomic classification scheme of Throndsen (1997), which was a partially modified classification of Christensen (1962, 1966). The recent taxonomic position of *Protaspis* is presented in accordance with Adl et al. (2005). Species names are listed in alphabetical order within each class (Table 1).

Results and discussion

Flagellated inhabitants of Kuwait's intertidal sediments were very diverse and mostly composed of sand-dwelling dinoflagellates, euglenids and cryptomonads. We identified a total of 67 flagellate species (Table 1, Figs 2–7); most of them being reported from Kuwait from the first time.

Table 1. List of species encountered during the survey of free-living flagellates associated with intertidal sediments along the coastline of Kuwait, 2005–2007. Abbreviations for substrate are as follows: 'M' – mud, 'MS' – muddy sand, 'S' – sand, 'P' – small saline ponds, 'MA' – macroalgae; categories of occurrence are: 'C' – common, 'F' – frequent, 'R' – rare; light microphotographs: figure numbers are followed by the numbers of the photographs.

Taxon	Substrate	Occurrence	Photograph
Class **Dinophyceae**			
Adenoides eludens (Herdman) Balech 1956	S	C	2:1–3
Amphidiniella sp.	S	R	2:4, 5
Amphidiniopsis arenaria Hoppenrath 2000	S	C	2:12, 13
Amphidiniopsis dentata Hoppenrath 2000	S	C	2:6–8
Amphidiniopsis swedmarkii (Balech) Dodge 1982	MS, S	C	2:9–11
Amphidinium carterae Hulbert 1957	MS, S	C	3:1
Amphidinium corpulentum Kofoid *et* Swezy 1921	S	R	3:19, 20
Amphidinium corrugatum Larsen *et* Patterson 1990	S	R	3:6–8
Amphidinium gibbosum (Maranda *et* Shimizu) Flø Jørgensen *et* Murray 2004	S	R	3:4
Amphidinium glabrum Hoppenrath *et* Okolodkov 2000	S	R	3:9, 10
Amphidinium herdmanii Kofoid *et* Swezy 1921	S	C	3:21, 22
Amphidinium incoloratum Campbell 1973	S	C	3:5
Amphidinium mootonorum Murray *et* Patterson 2002	S	C	3:15, 16
Amphidinium operculatum Claparède *et* Lachmann 1859	S	C	3:2
Amphidinium poecilochroum Larsen 1985	S	R	4:1
Amphidinium psittacus Larsen 1985	MS, S	F	4:2
Amphidinium scissum Kofoid *et* Swezy 1921	MS, S	C	3:11–14
Amphidinium semilunatum Herdman 1924	MS, S	C	3:18
Amphidinium steinii Lemmermann 1910	S	C	3:3
Amphidinium testudo Herdman 1924	S	R	3:17
Amphidinium sp. 1	S	R	4:3–5
Amphidinium sp. 2	S	R	4:6, 7
Bysmatrum teres Murray, Hoppenrath, Larsen *et* Patterson 2006	S	R	4:14–16
Coolia cf. *areolata* Ten-Hage, Turquet, Quod *et* Coutè 2000	S	R	2:16
Coolia monotis Meunier 1919	MA, S	R	2:14, 15
Gymnodinium venator Flø Jørgensen *et* Murray 2004	S	C	4:10, 11
Gyrodinium estuariale Hulburt 1957	M-S	C	4:8
Gyrodinium sp.	S	R	4:9
Herdmania litoralis (Dodge) Hoppenrath 2000	S	C	4:18, 19
Heterocapsa cf. *psammophila* Tamura, Iwataki *et* Horiguchi 2005	S	C	5:6–8
Heterocapsa sp.	S	C	4:12, 13
Katodinium asymmetricum (Massart) Loeblich 1965	MS, S	F	5:5
Katodinium glandula (Herdman) Loeblich 1965	S	C	5:1–4
Oxyrrhis marina Dujardin 1841	M-S	C	4:20, 21
Peridinium quinquecorne Abè 1927	S	R	4:17
Prorocentrum concavum Fukuyo 1981	MA, S	R	5:9–11
Prorocentrum fukuyoi Murray *et* Nagahama 2007	S	C	5:18, 19
Prorocentrum lima (Ehrenberg) Dodge 1975	MA, S	F	5:12, 13
Prorocentrum rhathymum Loeblich III, Sherley *et* Schmidt 1979	MA, S	R	5:14–17

Taxon	Substrate	Occurrence	Photograph
Roscoffia minor Horiguchi *et* Kubo 1997	S	R	5:20, 21
Sinophysis ebriolum (Herdman) Balech 1956	S	F	2:19
Sinophysis stenosoma Hoppenrath 2000	S	F	2:20
Thecadinium ovatum Yoshimatsu, Toriumi *et* Dodge 2004	S	R	2:17, 18
Class **Cryptophyceae**			
Platychilomonas psammobia Larsen *et* Patterson 1990	S	F	6:1, 2
Rhodomonas salina (Wislouch) Hill *et* Wetherbee 1989	MS, S	C	6:3–5
Class **Chlorophyceae**			
Dunaliella salina (Dunal) Teodoresco 1905	P	C	6:6, 7
Class Prasinophyceae			
Pyramimonas cf. *octopus* Moestrup *et* Kristiansen 1987	S	F	6:8, 9
Class Euglenophyceae			
Anisonema acinus Dujardin 1841	MS, S	C	6:12, 13
Chasmostoma nieuportense Massart 1920	M, MS	R	7:3
Dinema litorale Skuja 1939	S	F	6:10, 11
Dinema validum Larsen *et* Patterson 1990	M, MS	F	6:14–16
Eutreptia pertyi Pringsheim 1953	S	F	7:1
Eutreptiella sp.	S	R	7:2
Heteronema exaratum Larsen *et* Patterson 1990	MS	R	6:17, 18
Heteronema larseni Lee *et* Patterson 2000	S	C	6:19
Heteronema ovale Kahl 1928	S	F	6:20
Notosolenus ostium Larsen *et* Patterson 1990	MS, S	C	7:9
Petalomonas minor Larsen *et* Patterson 1990	M, MS	F	7:10, 11
Ploeotia heracleum Larsen *et* Patterson 1990	S	R	7:4
Ploeotia cf. *oblonga* Larsen *et* Patterson 1990	S	F	7:5
Ploeotia pseudoanisonema Larsen *et* Patterson 1990	M, MS	F	7:6, 7
Ploeotia sp.	S	F	7:8
Urceolus sabulosus Stokes 1886	M, MS	F	7:12–16
Cercozoa			
Protaspis grandis Hoppenrath *et* Leander 2006	S	C	7:17
Protaspis maior Skuja 1939	S	R	7:18
Protaspis obliqua Larsen *et* Patterson 1990	MS, S	C	7:19
Protaspis sp.	S	F	7:20, 21

The diversity of the flagellated group was mainly due to sand-dwelling dinoflagellates and euglenids. *Amphidinium*, with 17 species, was among the most abundant and diverse sand-dwelling dinoflagellate genera. Within this genus, the large, unarmored *A. scissum* was widely distributed throughout the year and may be the most abundant on Kuwait's intertidal sand flats. This species was occasionally found in other habitats.

A limited number of benthic dinoflagellates are potentially harmful, as they are capable of producing toxins, which may result in an intoxication of the marine environment. Among taxa of sand-dwelling dinoflagellates recorded in Kuwait were eight species that must be considered potentially harmful. *Prorocentrum concavum*

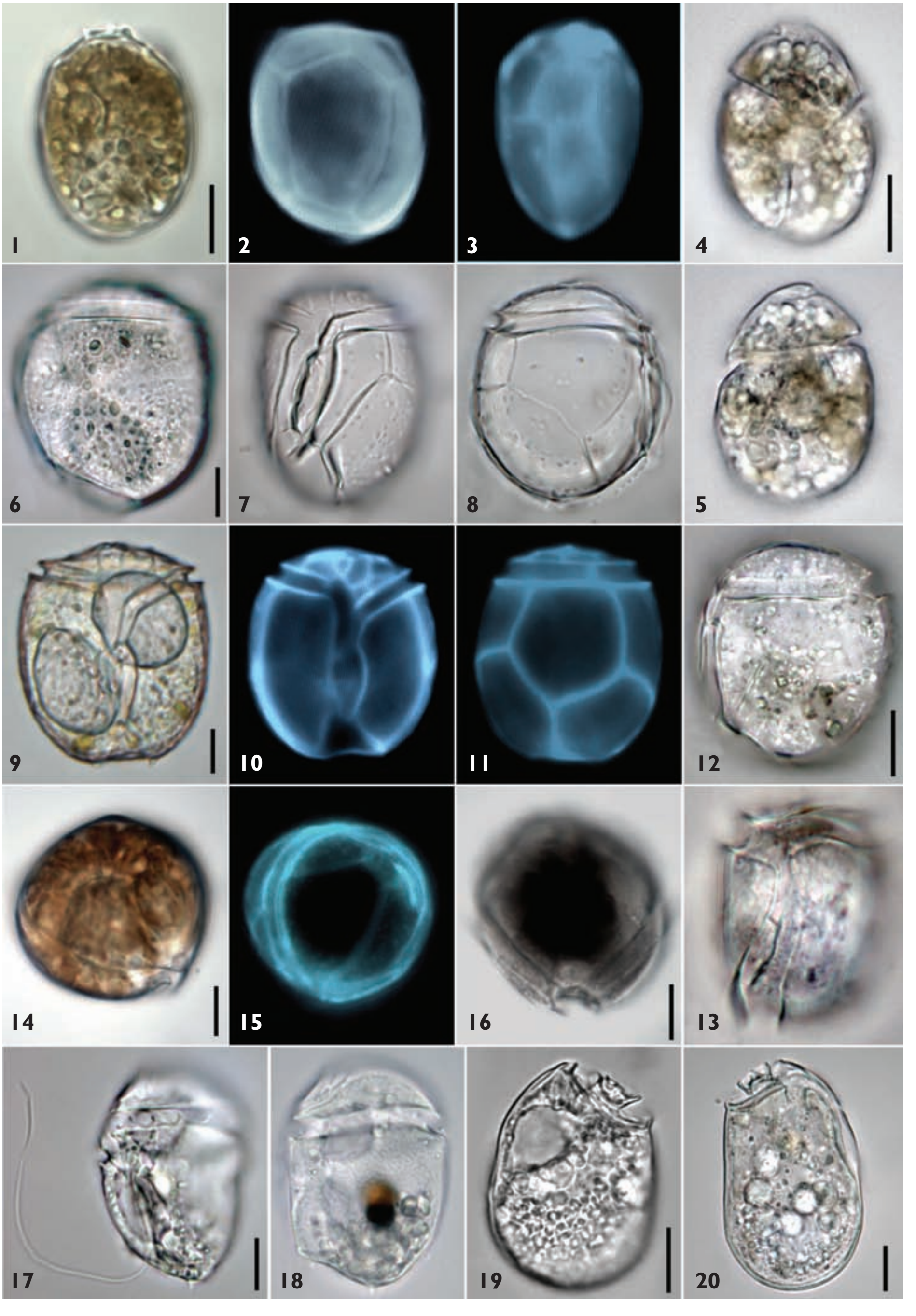

Figure 2. Light micrographs of the genera *Adenoides*, *Amphidiniella*, *Amphidiniopsis*, *Coolia*, *Thecadinium* and *Sinophysis*. **1–3** *Adenoides eludens* **4, 5** *Amphidiniella* sp. **6–8** *Amphidiniopsis dentata* **9–11** *Amphidiniopsis swedmarkii* **12, 13** *Amphidiniopsis arenaria* **14, 15** *Coolia monotis* **16** *Coolia* cf. *areolata* **17, 18** *Thecadinium ovatum* **19** *Sinophysis ebriolum* **20** *Sinophysis stenosoma*. Photos 2, 3, 10, 11, 15: epifluorescence. Scale bar = 10 μm for all photos.

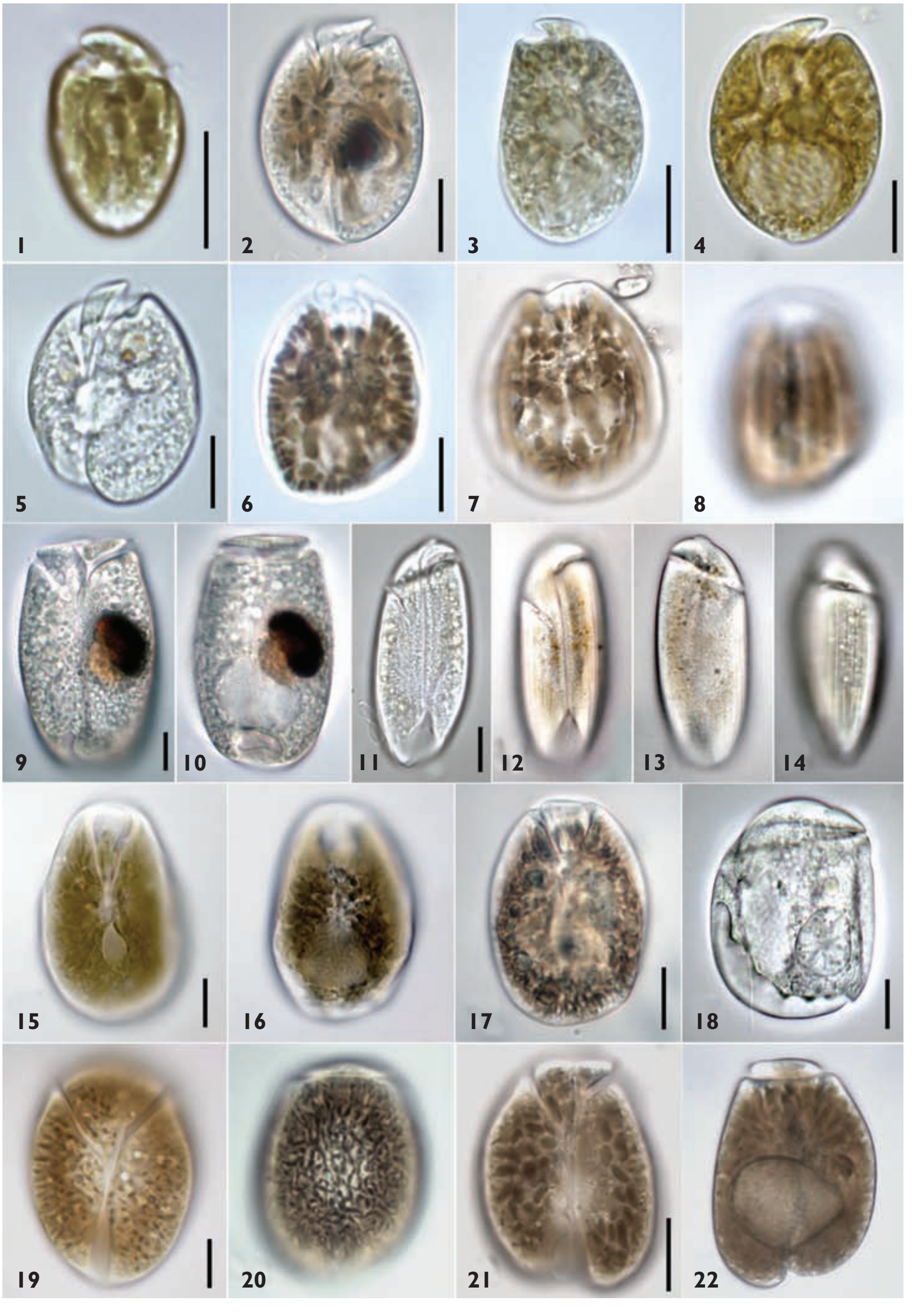

Figure 3. Light micrographs of the genus *Amphidinium*. **1** *Amphidinium carterae* **2** *Amphidinium operculatum* **3** *Amphidinium steinii* **4** *Amphidinium gibbosum* **5** *Amphidinium incoloratum* **6–8** *Amphidinium corrugatum* **9, 10** *Amphidinium glabrum* **11–14** *Amphidinium scissum* **15, 16** *Amphidinium mootonorum* **17** *Amphidinium testudo* **18** *Amphidinium semilunatum* **19, 20** *Amphidinium corpulentum* **21, 22** *Amphidinium herdmanii.* Scale bar = 10 µm for all photos.

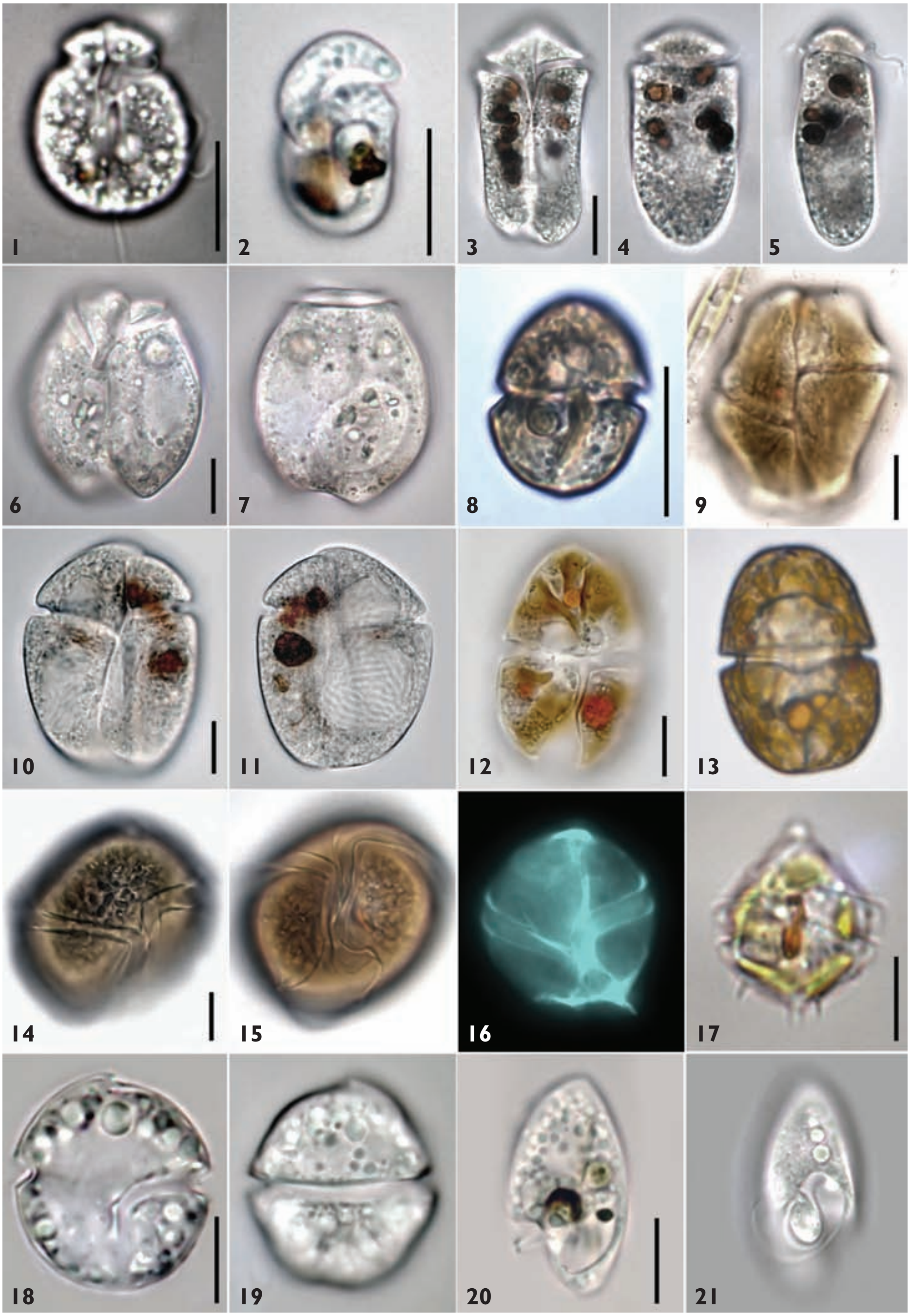

Figure 4. Light micrographs of the genera *Amphidinium*, *Gyrodinium*, *Gymnodinium*, *Heterocapsa*, *Bysmatrum*, *Peridinium*, *Herdmania* and *Oxyrrhis*. **1** *Amphidinium poecilochroum* **2** *Amphidinium psittacus* **3–5** *Amphidinium* sp. 1 **6, 7** *Amphidinium* sp. 2 **8** *Gyrodinium estuariale* **9** *Gyrodinium* sp. **10, 11** *Gymnodinium venator* **12, 13** *Heterocapsa* sp. **14–16** *Bysmatrum teres* **17** *Peridinium quinquecorne* **18, 19** *Herdmania litoralis* **20, 21** *Oxyrrhis marina.* Photo 16: epifluorescence. Scale bar = 10 µm for all photos.

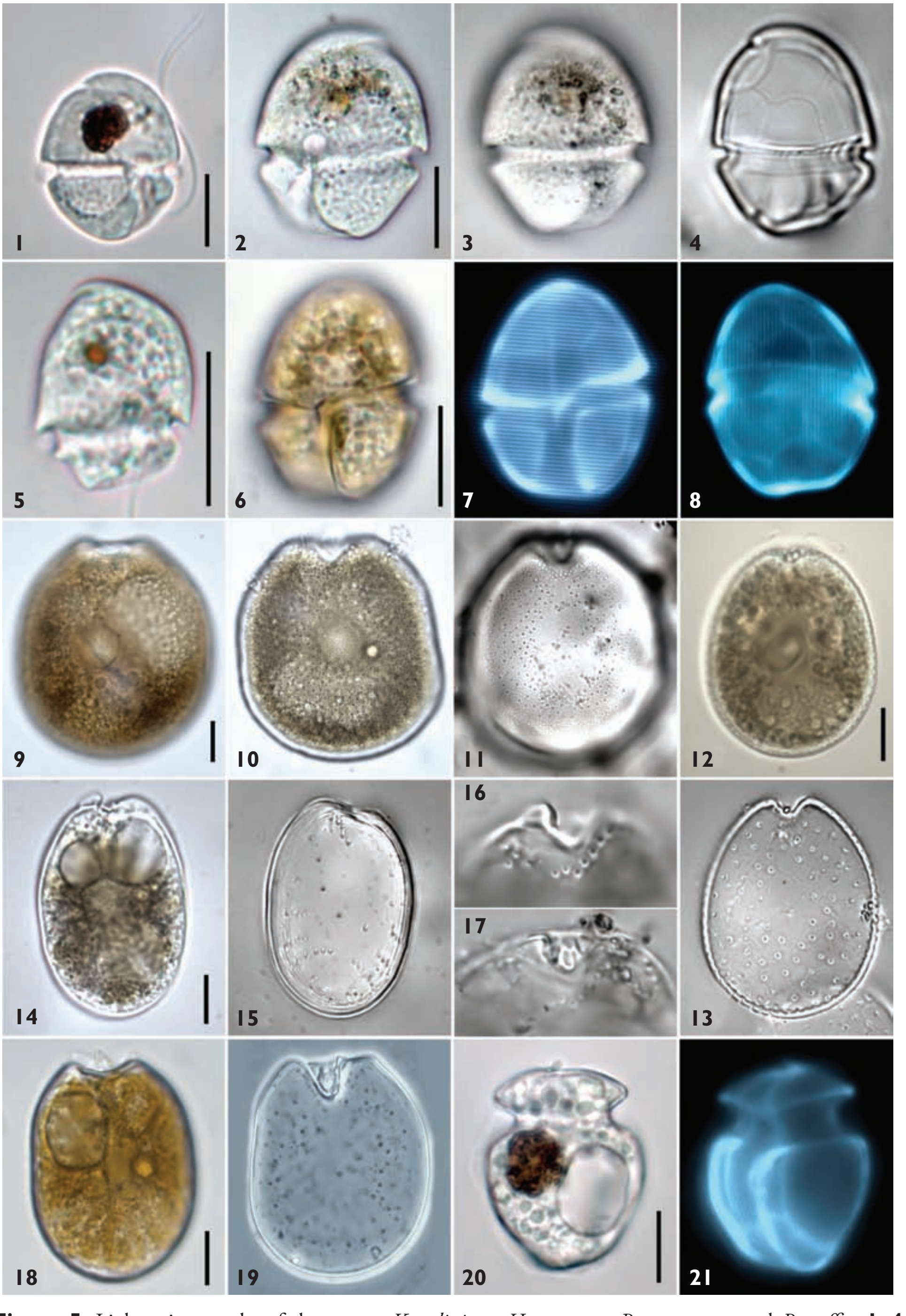

Figure 5. Light micrographs of the genera *Katodinium*, *Heterocapsa*, *Prorocentrum* and *Roscoffia*. **1–4** *Katodinium glandula* **5** *Katodinium asymmetricum* **6–8** *Heterocapsa* cf. *psammophila* **9–11** *Prorocentrum concavum* **12, 13** *Prorocentrum lima* **14–17** *Prorocentrum rhathymum* **18, 19** *Prorocentrum fukuyoi* **20, 21** *Roscoffia minor.* Photos 7, 8, 21: epifluorescence. Scale bar = 10 µm for all photos.

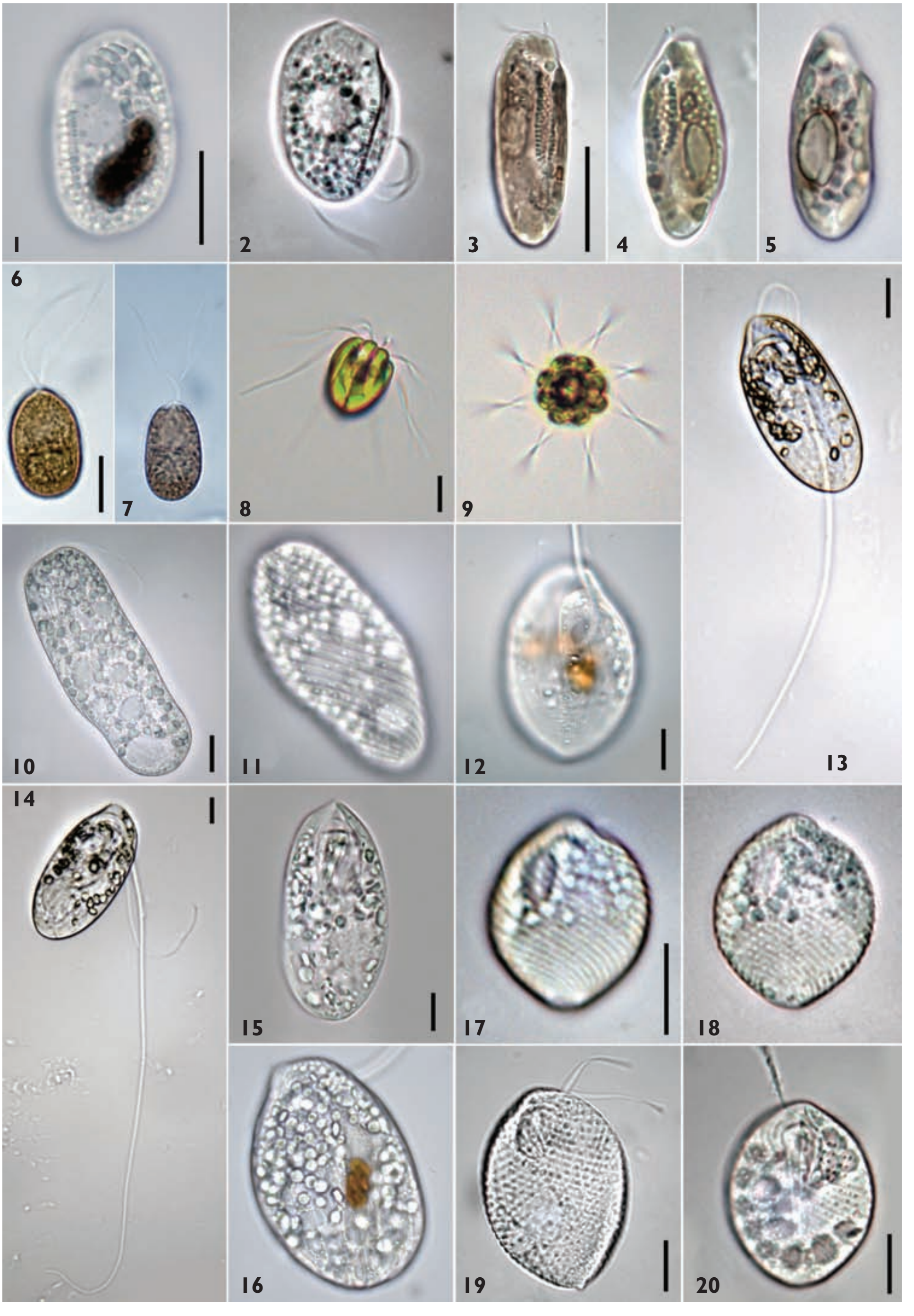

Figure 6. Light micrographs of the genera *Platychilomonas*, *Rhodomonas*, *Dunaliella*, *Pyramimonas*, *Dinema*, *Anisonema* and *Heteronema*. **1, 2** *Platychilomonas psammobia* **3–5** *Rhodomonas salina* **6, 7** *Dunaliella salina* **8, 9** *Pyramimonas* cf. *octopus* **10, 11** *Dinema litorale* **12, 13** *Anisonema acinus* **14–16** *Dinema validum* **17, 18** *Heteronema exaratum* **19** *Heteronema larseni* **20** *Heteronema ovale.* Scale bar = 10 µm for all photos.

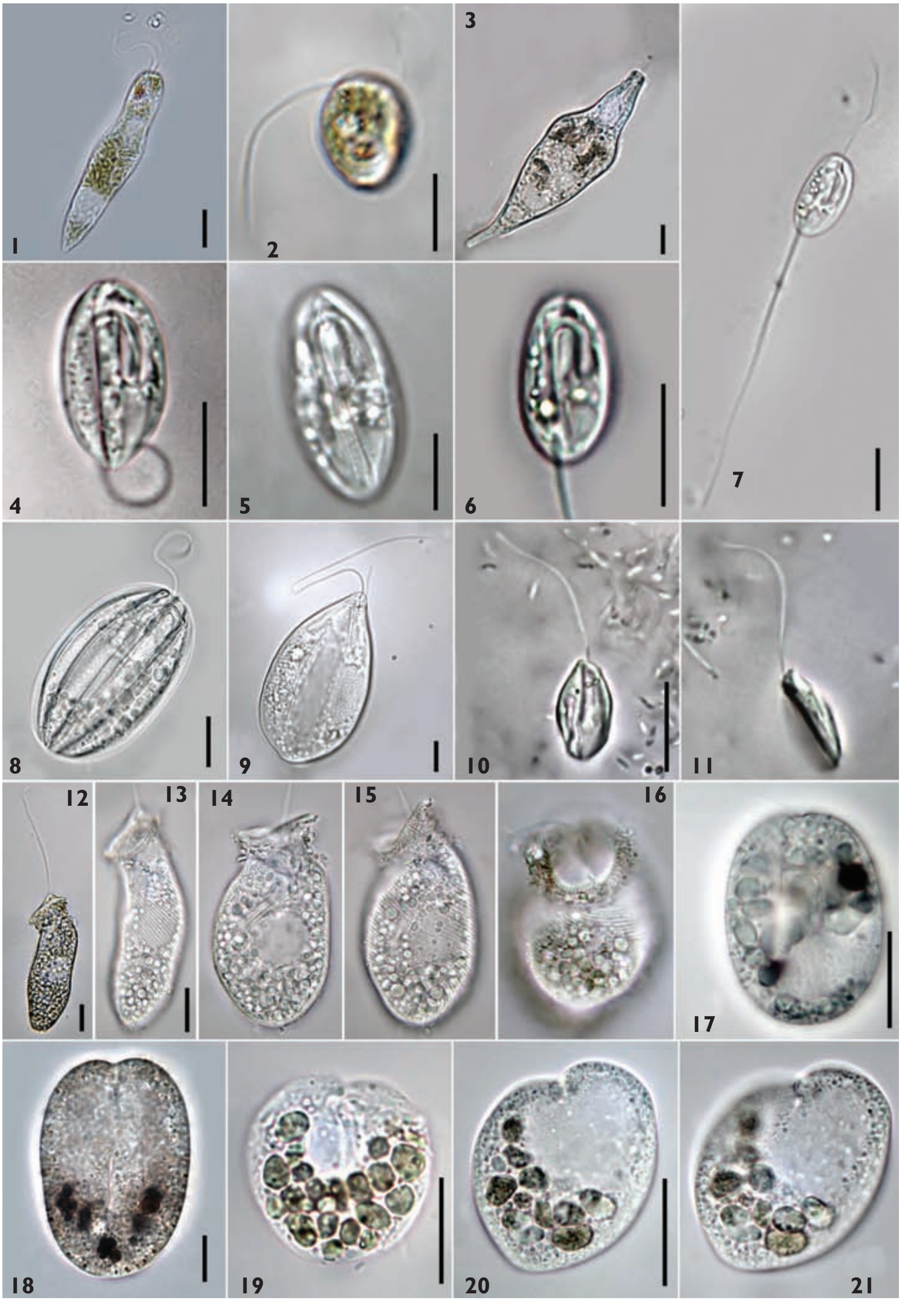

Figure 7. Light micrographs of the genera *Eutreptia*, *Eutreptiella*, *Chasmostoma*, *Ploeotia*, *Notosolenus*, *Petalomonas*, *Urceolus* and *Protaspis*. **1** *Eutreptia pertyi* **2** *Eutreptiella* sp. **3** *Chasmostoma nieuportense* **4** *Ploeotia heracleum* **5** *Ploeotia* cf. *oblonga* **6, 7** *Ploeotia pseudoanisonema* **8** *Ploeotia* sp. **9** *Notosolenus ostium* **10, 11** *Petalomonas minor* **12–16** *Urceolus sabulosus* **17** *Protaspis grandis* **18** *Protaspis maior* **19** *Protaspis obliqua* **20, 21** *Protaspis* sp. Scale bar = 10 μm for all photos.

has been reported to produce three diol esters of okadaic acid and ichthyotoxin (Yasumoto et al. 1987, Hu et al. 1993). *Prorocentrum lima* may produce okaidic acid and dinophysistoxins, which may cause diarrhetic shellfish poisoning (Murakami et al. 1982, Tindall et al. 1984, Torigoe et al. 1988, Lee et al. 1989, Hu et al. 1993). *Prorocentrum rhathymum* may produce water-soluble fast-acting toxins and hemolytic effects (Nakajima et al. 1981, Tindall et al. 1989). In the summer of 1999, a bloom of *P. rhathymum* (reported as *P. mexicanum*) caused a massive fish kill in Kuwait Bay (Al-Yamani et al. 2004). *Coolia monotis* is known to produce cooliatoxin, which is presumably related to yessotoxin (Holmes et al. 1995). It may be involved in ciguatera (Tindall and Morton 1998). Haemolysins, compounds toxic to fish, have been isolated from *Amphidinium carterae* (Yasumoto et al. 1987). *Amphidinium gibbosum* may produce cytotoxic metabolites, the most potent of which (caribenolide I) had anti-tumor effects (Bauer et al. 1994, Bauer et al. 1995a, b, Maranda and Shimizu 1996). Haemolytic and antifungal properties (amphidinols) are reported from *A. operculatum*; it may also be toxic to fish (Yasumoto et al. 1987). *Peridinium quinquecorne* can cause anoxia and fish kills, if occurring with very high cell densities (Fukuyo et al. 1990). These potentially harmful dinoflagellates were present in Kuwait's benthic microalgal community during 2005 to 2007, but never occurred in great numbers.

Euglenids comprised auto- and heterotrophic species. Among them, *Anisonema acinus* was the most common and widespread species in Kuwait's muddy and sandy sediments. *Petalomonas minor* and *Urceolus sabulosus* were mainly recorded in intertidal mudflats of Kuwait Bay, where they can be quite abundant.

The highest species diversity of flagellates in Kuwait's soft sediments was associated with the southern intertidal sand flats. Together with benthic diatoms and cyanobacteria, autotrophic flagellates are likely to be among the most important contributors to primary productivity in the intertidal zone. Heterotrophic species may play an important role in intertidal food webs, consuming even large diatoms and other flagellates.

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References

Adl SM, Simpson AGB, Farmer MA, Andersen RA, Anderson OR et al. (2005) The new high level classification of eukaryotes with emphasis on the taxonomy of Protists. *Journal of Eukaryotic Microbiology* 52: 399–451.

Al-Yamani FY, Bishop J, Ramadhan E, Al-Husaini M, Al-Ghadban AN (2004) Oceanographic atlas of Kuwait's waters. Kuwait: Kuwait Institute for Scientific Research. 203 pp.

Al-Zaidan ASY, Kennedy H, Jones DA, Al-Mohanna SY (2006) Role of microbial mats in Sulaibikht Bay (Kuwait) mudflat food webs: evidence from $\delta^{13}C$ analysis. *Marine Ecology Progress Series* 308: 27–36.

Bauer I, Maranda L, Shimizu Y, Peterson RW, Cornell L et al. (1994) The structures of amphidinolide B isomers: strongly cytotoxic macrolides produced by a free-swimming dinoflagellate, *Amphidinium* sp. *Journal of American Chemical Society* 116: 2657–2658.

Bauer I, Maranda L, Young KA, Shimizu Y, Fairchild C et al. (1995a) Isolation and structure of caribenolide I, a highly potent antitumor macrolide from a culture free-swimming Caribbean dinoflagellate, *Amphidinium* sp. *Journal of Organic Chemestry* 60: 1084–1086.

Bauer I, Maranda L, Young KA, Shimizu Y, Huang S (1995b) The isolation and structures of unusual 1,4-polyketides from the dinoflagellate, *Amphidinium* sp. *Tetrahedron Letters* 36: 991–994.

Christensen T (1962) Alger. In Böcher TW, Lange M, Sørenson T (eds) *Botanik. 2. Systematisk Botanik*. Copenhagen: Munksgaard, 1–178.

Christensen T (1966) Alger. In Böcher TW, Lange M, Sørenson T (eds) *Botanik. 2. Systematisk Botanik*. 2nd edn. Copenhagen: Munksgaard, 1–180.

Clayton DA (1986) Ecology of mudflats with particular reference to those of the northern Arabian Gulf. In Halwagy R, Clayton D, Behbehani M (eds) *Marine environment and pollution*. Oxford: Alden Press, 83–96.

Fritz L, Triemer RE (1985) A rapid simple technique utilizing calcofluor white MR2 for the visualization of dinoflagellate thecal plates. *Journal of Phycology* 21: 662–664.

Fukuyo Y, Takano H, Chihara M, Matsuoka K (1990) Red tide organisms in Japan: an illustrated taxonomic guide. Tokyo: Uchida Rokakuho. 401 pp.

Hendey NI (1970) Some littoral diatoms of Kuwait. *Nova Hedwigia Beihefte* 31: 101–168.

Hoffmann L (1996) Recolonisation of the intertidal flats by microbial mats after the Gulf War oil spill. In Krupp F, Abuzinada AH, Nader IA (eds) *A marine wildlife sanctuary for the Arabian Gulf: Environmental research and conservation following the 1991 Gulf War oil spill.* Frankfurt: NCWCD, Riyadh and Senckenberg Research Institute, 96–115.

Holmes JH, Lewis LJ, Hoy AWW (1995) Cooliatoxin, the first toxin from *Coolia monotis* (Dinophyceae). *Natural Toxins* 3: 355–362.

Hu T, deFreitas ASW, Doyle J, Jackson D, Marr J et al. (1993) New DSP toxin derivatives isolated from toxic mussels and the dinoflagellates, *Prorocentrum lima* and *Prorocentrum concavum*. In Smayda TJ, Shimizu Y (eds) *Toxic phytoplankton blooms in the sea*. Amsterdam: Elsevier Science Publishers B.V., 507–512.

Jones DA (1986a) A field guide to the sea shore of Kuwait and the Arabian Gulf. UK: University of Kuwait, Blandford Press. 192 pp.

Jones DA (1986b) Ecology of the rocky and sandy shores of Kuwait. In Halwagy R, Clayton D, Behbehani M (eds) *Marine environment and pollution*. Oxford: Alden Press, 69–81.

Lee J-S, Igarashi T, Fraga S, Dahl E, Hovgaard P et al. (1989) Determination of diarrhetic shellfish toxins in various dinoflagellate species. *Journal of Applied Phycology* 1: 147–152.

Maranda L, Shimizu Y (1996) *Amphidinium operculatum* var. nov. *gibbosum* (Dinophyceae), a free-swimming marine species producing cytotoxic metabolites. *Journal of Phycology* 32: 873–879.

Murakami Y, Oshimata Y, Yasumoto T (1982) Identification of okadaik acid as a toxic component of a marine dinoflagellate *Prorocentrum lima*. *Bulletin of Japanese Society of Scientific Fisheries* 48: 69–72.

Nakajima I, Oshima Y, Yasumoto T (1981) Toxicity of benthic dinoflagellates in Okinawa. *Bulletin of Japanese Society of Scientific Fisheries* 47: 1029–1033.

Throndsen J (1997) The planktonic marine flagellates. In Tomas CR (Ed.) *Identifying Marine Phytoplankton*. San Diego: Academic Press, 591–710.

Tindall DR, Morton SL (1998) Community dynamics and physiology of epiphytic/benthic dinoflagellates associated with ciguatera. In Anderson DM et al. (eds) *Physiological ecology of harmful algal blooms*. NATO ASI series, Ser. G, Ecological Sciences, v. 41. Berlin: Springer-Verlag, 291–313.

Tindall DR, Dickey RW, Carlson RD, Morey-Gaines G (1984) Ciguatoxigenic dinoflagellates from the Caribean Sea. In Ragelis EP (Ed.) *Seafood toxins*. Washington D.C.: American Chemical Society, 225–240.

Tindall DR, Miller DM, Bomber JW (1989) Culture and toxicity of dinoflagellates from ciguatera endemic regions of the world. *Toxicon* 27: 83.

Torigoe K, Murata M, Yasumoto T (1988) Prorocentrolide, a toxic nitrogenous macrocycle from a marine dinoflagellate, *Prorocentrum lima*. *Journal of American Chemical Society* 110: 7876–7877.

Uhlig G. (1964) Eine einfache Methode zur Extraktion der vagilen, mesopsammalen Microfauna. *Helgolander Wissenschaftliche Meeresuntersuchungen* 11: 178–185.

Yasumoto T, Seino N, Murakami Y, Murata M (1987) Toxins produced by benthic dinoflagellates. *Biological Bulletin* 172: 128–131.

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RESEARCH ARTICLE

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Key Biodiversity Areas: Rapid assessment of phytoplankton in the Mesopotamian Marshlands of southern Iraq

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Abstract

Between the summers of 2005 and 2007, studies have been conducted for five seasons in several marsh locations in southern Iraq. During five surveys, 317 taxa of phytoplankton belonging to six major groups were identified. These included: 204 taxa of Bacillariophyceae (represented by 13 Centrales and 191 Pennales, thus 14% and 27% respectively of all taxa recorded), 59 Chlorophyta (28%), one Cryptophyta (4%), 39 Cyanophyta (21%), 10 Euglenophyta (2%) and four Pyrrophyta (4% of all the taxa recorded). The Central Marsh, Hammar Marsh and the Hawizeh Marsh had higher phytoplankton populations compared to all other studied sites. The dominant phytoplankton groups throughout the study area were the Bacillariophyceae, Chlorophyta and Cyanophyta. The dominant species were *Cyclotella meneghiniana*, *Kirchneriella irregularis* and *Nitzschia palea.* A progression in the richness and biodiversity of species occurred during winter. These three phytoplankton groups were dominant in waters of southern Iraq and were responsible for most of the species richness and diversity observed. Generally, sites changed from summer to winter according to the changing conditions associated with nutrients, salinity, temperature, and light intensity. These controlling factors influenced phytoplankton biomass from season to season.

Keywords

Phytoplankton, Iraq, marshlands

Introduction

Aquatic ecosystems are dynamic with several biotic and abiotic variables changing in space and time. From 2005 to 2007, after reflooding of the southern marshes, the Key Biodiversity Areas (KBA) project led by Nature Iraq undertook ecological surveys of flora and fauna across southern Iraq (Rubec and Bachmann 2008). The KBA Project was involved a rapid assessment in several marshes to understand changes that took place in the physicochemical characteristics of the marshes and consequently changes in phytoplankton composition. Most of the surveys occurred in the Central Marsh, Hammar Marsh, Hawizeh Marsh, Middle Euphrates, the Khor al-Zobayr, the Seasonal Marshes and the Shatt al-Arab. Although, the phytoplankton flora in some of these marshes has been studied previously, the present study contributes new information on the current status of phytoplankton populations and their diversity in these ecosystems. This is in relation to physicochemical characteristics of these waters after several decades of major environmental degradation caused by conflict, dam building in the Tigris-Euphrates Basin and directed drainage by the previous regime.

Wetlands are ecosystems in which the soil, despite periodic fluctuations in water level, is more or less continuously waterlogged. Non-marine wetlands generally have a water depth less than 2 m and, by this definition comprise as much as 6% of the land area of the earth's surface (Mitsch and Gosselink 1993). Studies have shown that marshes are suitable areas for the growth of several types of algae and higher aquatic plants. The marshes of southern Iraq seem especially suitable for growth of algae so that they diversify widely due to the shallow waters, the slow flow of the water attributable to low gradients and suitable nutrient concentrations and temperatures (Yaaqub 1992). Therefore, these algae have been widely used for water quality monitoring, and as they are primary producers, they are easily affected by physical and chemical variations in their environment (Bartram and Balance 1996).

Temporal and spatial distributions of phytoplankton are determined by a variety of environmental factors, including sunlight, the availability of essential nutrients and water temperature. Hinton and Maulood (1980, 1982) showed that at least 77 diatom taxa and 101 non-diatom taxa are known from the brackish waters of southern Iraq, the Shatt al-Arab and the Hammar Marsh. A total of 129 algal species and 63 genera were in the marshes near Qurna (Pankow et al. 1979, Al-Saboonchi et al. 1982). Some 72 Bacillariophyta, 28 Chlorophyta, 26 Cyanophyta, two Euglenophyta, and one Cryptophyta have been recorded in Hammar Marsh (Nurul-Islam 1982). Dinoflagellates have also been recorded in the marshes (Evans 2001).

Materials and methods

For qualitative studies of phytoplankton, samples were taken by a phytoplankton net manufactured by Hydro-Bios (23 µm in pore diameter), which was placed into the water 10 to 15 cm below the water surface and pulled at an appropriate speed for 10 to15 min. The phytoplankton collected was transferred to a polyethylene container and preserved by adding Lugol's solution at a ratio of 1:100 with 40% formaldehyde until analyzed in the laboratory. The non-diatoms were identified by taking a drop of the sample on a slide with a slide cover, and then examined using a compound microscope (x10, x40 and x100). For diatom identification, a water sample was mixed with an equal volume of nitric acid in a 15 ml test tube to dissolve the organic matter surrounding the diatoms. The diatoms were precipitated by centrifuge and permanent slides were made using Canada balsam or Naphrax and a hot plate (Patrick and Riemer 1975).

For the quantitative study of phytoplankton, one-liter water samples were collected in polyethylene containers and preserved with a Lugol/formaldehyde solution (as described above). Following sedimentation the total number of phytoplankton organisms was counted (Furet and Benson-Evans 1982). Permanent slides were prepared and diatoms were identified using a compound microscope. Smith (1950), Prescott (1944, 1982) and Thompson (1959) were references used in phytoplankton identification. The Shannon-Wiener Diversity Index (H) was used to determine the diversity and compare among stations. This was done using the statistical software CANOCO 4.5 package (Ter Braak and Šmilauer 2002); the equation is:

$$H = -\sum (Ni/N)^* \ Ln \ ^*(Ni/N)$$

N = the hall summation of species density in the single station
Ni = density of single species

Study area

Most of the field sites in southern Iraq had not been surveyed since at least 1979 or earlier. An initial February and March 2005 survey was restricted to seven sites in southern Iraq. It was limited by practical and security issues in that period and seen as a start-up, experience-building exercise. All other southern KBA sites were included in the subsequent 2005 through 2007 surveys. In order to facilitate field survey logistics, seven major wetland areas as shown in Fig. 1 and Table 1 were defined.

Results and discussion

Throughout the five surveys conducted, 317 phytoplankton taxa belonging to six major algal categories were identified. These include 204 Bacillariophyceae (13 Centrales and 191 Pennales representing 14% and 27% of the total taxa recorded respectively); 59 Chlorophyta (28% of all taxa recorded); one Cryptophyta (4%); 39 Cyanophyta (21%); 10 Euglenophyta (2%); and 4 Pyrrophyta (4%).

During summer 2005 survey, Cyanophyta had the highest total count (90,207.1 × 10^3 cells L^{-1}). The dominant Cyanophyta species were *Anabaena* sp., *Microcystis aeruginosa*, *Merismopedia convolute*, *Oscillatoria geitleri*, *Oscillatoria limnetica*, and *Lyngbya*

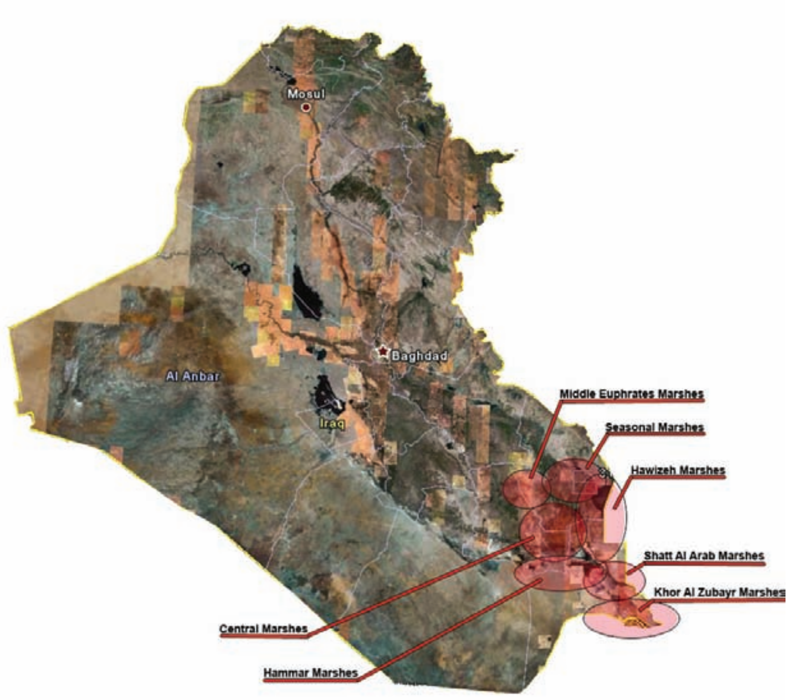

Figure 1. Major wetlands of southern Iraq indicating specific locations of marshes surveyed for phytoplankton assessment.

Table 1. The seven major wetland areas of southern Iraq.

Major Wetland Area	Area	Governorates
Hammar Marshes (HA)	20 field sites covering 350,000 ha	Thi Qar, Basrah
Central Marshes (CM)	24 field sites covering 705,000 ha	Thi Qar, Wasit, Missan
Hawizeh Marshes (HZ)	Seven sites covering 235,000 ha	Missan
Mesopotamian Marshes (MP)	Four field sites covering 30,000	Muthanna, Babil, Wasit
Seasonal Marshes (SM)	Five sites covering 5,200 ha	Missan
Shatt al-Arab Marshes (SA)	Four sites covering 16,500 marshes	Basrah
Khour al-Zobayr Marshes (KZ)	Four sites covering 20,000 ha	Basrah

limnetica. These genera of Cyanophyta are known for their ability to produce potential toxic substances especially *Anabaena*, *Lyngbya* and *Microcystis* (Sivonen and Jones 1999, Carmichael 2001). These species are also among the most abundant Cyanophyta in fresh and brackish waters (Huisman et al. 2005). *Microcystis* possesses gas vesicles that make them buoyant. This characteristic may have aided in the dominance of this species because it allows it to receive more light than species lacking gas vesicles (Seckbach 2007). Most of these dominant Cyanophyta prefer relatively alkaline, warmer, saline and nutrient-rich waters (Wehr and Sheath 2003, Al-Saadi and Sulaiman 2006).

The Cyanophyta were followed in abundance by the diatoms, Chlorophyta and Pyrrophyta, as shown in Appendix 1.

During both the winter and summer 2006 surveys, Chlorophyta had the highest total counts (37,308.9 × 10^3 cells L^{-1} and 23,180.8 × 10^3 cells L^{-1} respectively). The Chlorophyta is known to occur primarily in freshwater. It was mainly dominated by *Kirchneriella irregularis*, *Scenedesmus quadricauda*, *Monoraphidium contortum* and *Coelastrum astroideum.* Non-motile chlorophytes were a component of the plankton community (e.g. *Monoraphidium*, *Coelastrum* and *Scenedesmus*). Under moderate conditions, these species are most abundant in freshwater ecosystems especially during the summer, when light and temperature are near their seasonal maximum and nutrients become a limiting factor. The diatoms followed the chlorophytes during both seasons in terms of abundance (41,804.5 × 10^3 cells L^{-1}) and were dominated by *Cyclotella atomus*, *Cyclotella meneghiniana*, *Achnanthes minutissima*, *Fragilaria ulna*, *Fragilaria vaucheriae*, *Nitzschia gracilis*, *Nitzschia longissima* and *Nitzschia palea. Cyclotella meneghiniana* is known to prefer relatively slow flowing, saline and alkaline waters (Stoermer and Smol 2004).

Achnanthes minutissima was one of the dominant pennate diatoms probably because this species is physiologically more active than larger diatom cells. This would partly be due to its large surface to volume ratios (Allen 1977). Usually, dominant algal groups of nutrient-rich, temperate freshwater wetlands include pennate diatoms, typically genera such as *Achnanthes*, *Fragilaria*, *Navicula* and *Nitzschia* (Stevenson et al. 1996). In the winter 2007 survey, Bacillariophyceae/Pennales had the highest total count (29,674.2 × 10^3 cells L^{-1}). The dominant species was *Nitzschia palea,* one of the most common species in this genus, which is often found in organically polluted waters (Palmer 1969). In addition, *Oscillatoria limnetica* was the main cyanophyte, *Peridinium cinctum* the main dinoflagellate and *Kirchneriella irregularis* the main chlorophyte observed. In the summer of 2007 survey, the chlorophytes that had the highest total counts (54,473.4 × 10^3 cells L^{-1}) were *Kirchneriella irregularis*, *Scenedesmus quadricauda* and *Monoraphidium convolutum.*

Generally, in all of these surveys, the highest cell concentrations were in the Central Marsh, Hammar Marsh and Hawizeh Marsh (Table 2). Among the 24 sites in the Central Marsh, those with the highest diversity were Al Kinziryi, the Al Hammar Area and Al Fhood. From the 20 sites in the Hammar Marsh, the most diverse site was Al Sallal. Ojayradah was the most diverse site among the seven sites in the Hawizeh Marsh.

Therefore, algal assemblages may differ between restored and extant wetlands and could be valuable indicators of restoration success because algal species composition and diversity would differ in low- and high-nutrient wetlands (John 1993, Mayer and Galatowitsch 1999 as cited in Stevenson et al. 2006). Sites obviously also revealed changes from summer to winter, associated with changes in nutrients, temperature and light intensity. Therefore, changes in seasonality as shown by varying environmental variables could strongly affect phytoplankton variability (Abdul-Hussein and Mason 1988). Variations in the annual temperature regime appear to be the major cause of temporal variability of phytoplankton in the area, as observed by Gayoso (1998).

Table 2. Total count (× 10^3 cell L^{-1}) and percentage of identified phytoplankton groups in locations surveyed during summer 2005 to summer 2007. Major wetland areas: Hammar Marshes (HA), Central Marshes (CM), Hawizeh Marshes (HZ), Mesopotamian Marshes (MP), Seasonal Marshes (SM), Shatt al-Arab Marshes (SA), Khor al-Zobayr Marshes (KZ).

Survey	Sites	Bac./ Centrales		Bac./ Pennales		Chloro-phyta		Crypto-phyta		Cyano-phyta		Eugleno-phyta		Pyrro-phyta	
		T. C.	%	T. C.	%	T. C.	%	T. C.	%	T. C.	%	T. C.	%	T. C.	%
Summer 2005	CM	10598.6	43.3	19385.0	49.5	22602.7	56.9	2917.5	87.9	43060.4	47.7	1751.3	65.2	457.0	3.0
	HA	10282.8	42.0	9820.5	25.1	12346.9	31.1	355.3	10.7	31237.5	34.6	821.2	30.6	499.2	3.3
	HZ	340.9	1.4	4328.4	11.1	4387.5	11.1	46.3	1.4	11983.1	13.3	112.9	4.2	294.1	1.9
	SA	2877.4	11.8	3917.0	10.0	347.4	0.9	0.0	0.0	654.2	0.7	0.0	0.0	54.4	0.4
	KZ	270.1	1.1	154.4	0.4	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
	MP	91.0	0.4	1556.3	4.0	10.1	0.0	1.0	0.0	3271.9	3.6	1.0	0.0	13903.9	91.4
	SM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	24460.8	100.0	39161.6	100.0	39695.6	100.0	3320.1	100.0	90207.1	100.0	2686.4	100.0	15210.6	100.0
Winter 2006	CM	9436.7	79.6	20155.6	53.5	35860.9	96.1	2889.2	33.2	1778.0	19.0	2756.8	77.9	193.3	31.8
	HA	311.5	2.6	6394.7	17.0	86.7	0.2	19.2	0.2	733.8	7.8	0.0	0.0	19.2	3.2
	HZ	1114.1	9.4	6305.5	16.7	980.2	2.6	4710.1	54.0	6313.4	67.5	733.7	20.7	151.2	24.9
	SA	581.9	4.9	2278.5	6.0	363.0	1.0	751.8	8.6	219.5	2.3	37.2	1.1	226.4	37.2
	KZ	133.6	1.1	214.6	0.6	0.0	0.0	0.0	0.0	271.7	2.9	9.1	0.3	9.1	1.5
	MP	279.4	2.4	2321.8	6.2	18.1	0.0	344.2	3.9	38.2	0.4	0.0	0.0	9.1	1.5
	SM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	11857.2	100.0	37670.7	100.0	37308.9	100.0	8714.5	100.0	9354.6	100.0	3536.8	100.0	608.3	100.0
Summer 2006	CM	3752.7	20.0	7209.2	31.3	17254.7	74.4	2128.6	97.5	3539.6	22.1	652.4	48.2	2256.2	48.4
	HA	11638.3	61.9	7063.5	30.7	1575.4	6.8	54.3	2.5	865.8	5.4	511.5	37.8	1703.6	36.5
	HZ	280.1	1.5	3654.1	15.9	2778.2	12.0	1.0	0.0	11223.9	70.1	178.2	13.2	112.8	2.4
	SA	2769.8	14.7	4440.5	19.3	1073.2	4.6	0.0	0.0	366.6	2.3	0.0	0.0	72.4	1.6
	KZ	249.9	1.3	262.1	1.1	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	479.9	10.3
	MP	102.2	0.5	382.1	1.7	499.3	2.2	0.0	0.0	19.1	0.1	12.1	0.9	36.2	0.8
	SM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	18793.0	100.0	23011.5	100.0	23180.8	100.0	2183.9	100.0	16016.0	100.0	1354.2	100.0	4661.1	100.0

Survey	Sites	Bac./ Centrales T. C.	%	Bac./ Pennales T. C.	%	Chloro- phyta T. C.	%	Crypto- phyta T. C.	%	Cyano- phyta T. C.	%	Eugleno- phyta T. C.	%	Pyrro- phyta T. C.	%
Winter 2007	**CM**	9861.7	63.6	11345.6	38.2	8166.7	42.6	5869.2	64.8	455.2	7.1	56.5	5.4	905.5	22.6
	HA	1946.3	12.5	5734.9	19.3	8605.9	44.9	1240.9	13.7	1486.8	23.3	81.5	7.7	2571.6	64.2
	HZ	1771.9	11.4	4102.8	13.8	1495.8	7.8	1023.4	11.3	3691.3	57.9	0.0	0.0	199.3	5.0
	SA	528.0	3.4	2334.7	7.9	299.1	1.6	289.7	3.2	83.6	1.3	63.4	6.0	108.8	2.7
	KZ	1161.8	7.5	153.6	0.5	434.9	2.3	625.0	6.9	489.2	7.7	272.7	25.9	153.9	3.8
	MP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SM	247.9	1.6	6002.6	20.2	154.0	0.8	9.1	0.1	173.2	2.7	579.7	55.0	63.4	1.6
	Total	15517.6	100.0	29674.2	100.0	19156.4	100.0	9057.3	100.0	6379.3	100.0	1053.8	100.0	4002.5	100.0
Summer 2007	**CM**	5206.2	33.8	25491.5	68.0	33188.9	60.9	878.5	39.0	455.2	10.1	880.3	73.7	626.2	31.5
	HA	8125.3	52.8	7133.0	19.0	13017.4	23.9	1222.8	54.2	2230.2	49.4	283.1	23.7	743.7	37.4
	HZ	191.1	1.2	1501.5	4.0	7655.6	14.1	126.8	5.6	1026.8	22.8	11.1	0.9	126.9	6.4
	SA	1480.0	9.6	1416.3	3.8	542.9	1.0	9.1	0.4	763.8	16.9	0.0	0.0	55.4	2.8
	KZ	134.6	0.9	121.3	0.3	28.2	0.1	0.0	0.0	9.1	0.2	0.0	0.0	63.4	3.2
	MP	244.9	1.6	1842.7	4.9	40.4	0.1	18.1	0.8	27.2	0.6	19.2	1.6	371.4	18.7
	SM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	15382.1	100.0	37506.3	100.0	54473.4	100.0	2255.3	100.0	4512.3	100.0	1193.7	100.0	1987.0	100.0

According to richness and diversity indicators, the authors observed that there is an improvement in water quality in the southern Iraqi marshes especially in winter. This may be attributed to the fact that in winter nutrient levels are higher due to seasonally higher rainfall and thus higher runoff from the surrounding lands. Oxygen concentrations are also higher at lower temperatures. Canonical Correspondence Analysis (CCA) was used to elucidate the relationships between biological assemblages of the phytoplankton samples and their environment to determine the phytoplankton richness and diversity in the marshes. As a result, there was an increase in the phytoplankton richness and diversity of these marshes, as illustrated in Figs 2 and 3.

Each object shape in Fig. 2 demonstrates a phytoplankton sample obtained during the surveys, indicating the diversity and richness during the five surveys. Diversity and richness values of the first two surveys during the summer of 2005 and the winter of 2006 were scattered compared with the values recorded during the 2007 winter and summer, where they started to develop and increase in numbers.

Fig. 3 demonstrates that the phytoplankton diversity ranged between 1.6–2.1 during summer 2005 and winter 2006, while diversity values became higher during the following surveys ranging between 2.1 and 2.4, meaning that the diversity increased.

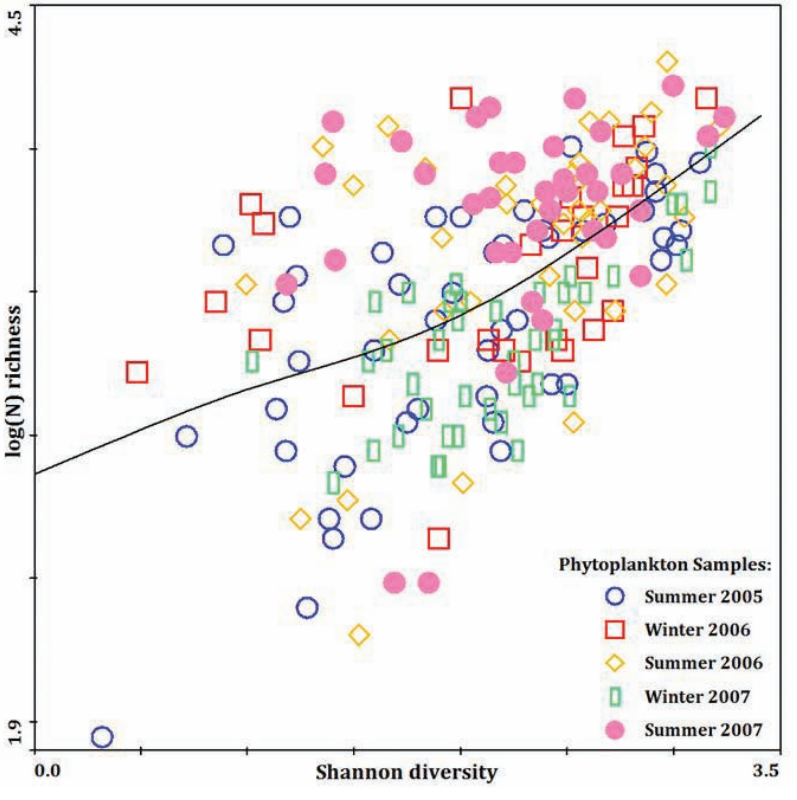

Figure 2. Seasonal phytoplankton diversity and richness in all sites.

It is clear that the diversity during the first two surveys was lower compared to the following surveys where the diversity began to even out and fluctuate to a lesser degree. The increase in the phytoplankton diversity and richness were most likely related to the environmental conditions that also started getting more stable.

An important reason for the success of certain algal species in wetland habitats is their ability to tolerate variations in water level and desiccation. Water levels may fluctuate several times in a few months or persist for several years. Algae that are subjected to a variable moisture regime must have the capacity to adapt to tolerate the extremes of these environmental conditions (Wehr and Sheath 2003). Thus, many factors may contribute to phytoplankton diversity and production in wetlands, including nutrients, temperature, light, macrophytes, etc. (Stevenson et al. 1996). As in other water bodies, nutrient conditions, climate, and geology influence species composition but in wetlands, water level, plant composition and degree of mixing with other water bodies are also important for the phytoplankton community (Goldsborough and Robinson 1996).

In the southern Iraqi marshes, the authors observed that diatoms, Chlorophyta and Cyanophyta were the dominant phytoplankton groups, which agrees with the findings of Goldsborough and Robinson (1996).

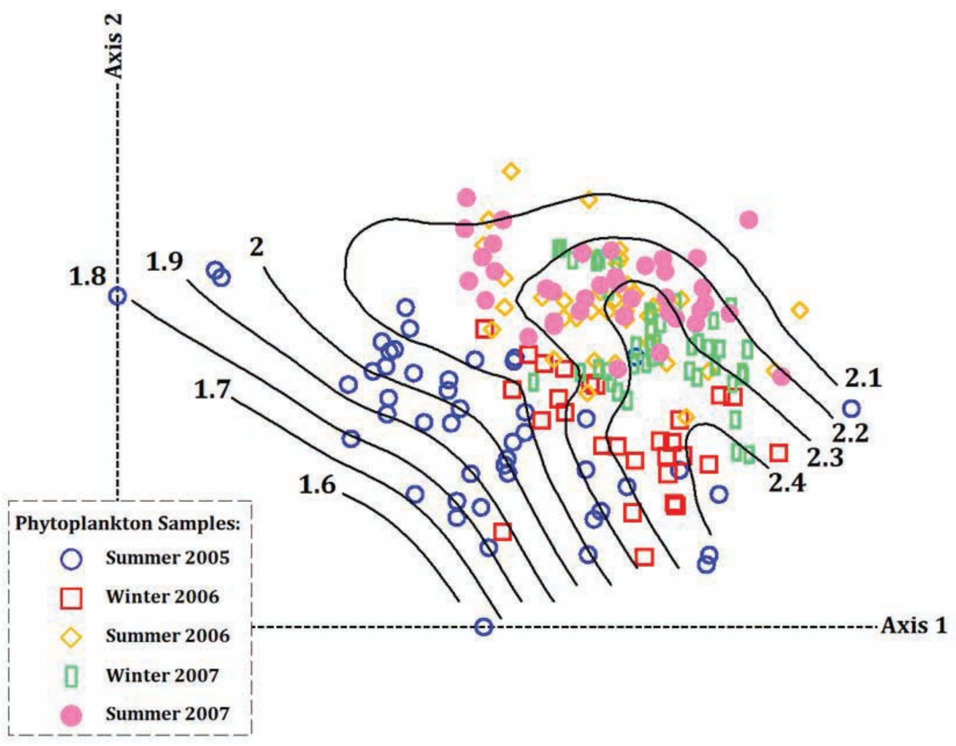

Figure 3. Seasonal phytoplankton diversity contour in all sites.

Conclusions and recommendations

The main conclusions from these studies are:

The phytoplankton groups that dominate the southern marshes are diatoms, Chlorophyta and Cyanophyta, with other groups having a low number of species;

In all sites of the southern marshes of Iraq studied, especially in the Central Marsh, Hammar Marsh and Hawizeh Marsh, phytoplankton richness and diversity increased from 2005 to 2007.

Based on these studies, several recommendations relevant to the management of the marshes of southern Iraq are made by the authors:

Phytoplankton should be used for ongoing biological monitoring and as indicators for organic pollution in the marshes;

The controlling factors influencing phytoplankton biomass may vary from season to season and phytoplankton biomass may be more sensitive and responsive to environmental variables in winter and summer as compared to autumn and spring. Monitoring programs should be flexible to allow for adjustment to these changing environmental conditions;

Monitoring studies should focus on the main parameters that have the greatest effects on the phytoplankton community. These are: light penetration, temperature, pH, water flow, nutrient levels and land use, in particular for water buffalo and cattle grazing.

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References

Abdul-Hussein MM, Mason CF (1988) The phytoplankton community of a eutrophic reservoir. Hydrobiologia 169: 265–277.

Allen TFH (1977) Scale in microscopic algal ecology: a neglected dimension. Phycologia 16:253–257. Cited in Wehr JD, Sheath RG (2003).

Al-Saadi HA, Sulaiman NA (2006) Phycology. Amman, Jordan: Al-Yazori Press. (In Arabic).

Al-Saboonchi AA, Mohammed ARM, Barak NA (1982) A study of phytoplankton in the Garma Marshes, Iraq. Iraqi J. Mas.Sci.1(1): 67–78.

Bartram J, Balance R (Eds) (1996) Water Quality Monitoring: Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes. London, United Kingdom: E and F.N. Spon Co.,

Carmichael WW (2001) A mini-review of cyanotoxins, toxins of cyanophyta (blue-green algae). Cited in de Koe et al. (2005).

Chorus I, Bartram J (Eds) (2005) Toxic Cyanophyta in Water: A Guide to Their Public Health Consequences, Monitoring and Management. London, United Kingdom: E. and F.N. Spon Co. Cited in Huisman et al. (2005).

De Koe WJ, Samson RA, van Egmond HP, Gilbert J, Sabino M (Eds) (2005) Mycotoxins and Phycotoxins in Perspective at the Turn of the Millennium. Wageningen, The Netherlands: Ponsen and Looyen Inc. pp. 495–504. in Huisman et al. (2005).

Edmonston WT (1959). Freshwater Biology. New York, USA: John Wiley and Sons, Inc.

Evans MI (2001) The Ecosystem in Iraqi Marshlands: Prospects. Proceedings of a Conference of the AMAR International Charitable Foundation. London, United Kingdon.

Furet JE, Benson-Evans K (1982) An evaluation of the time required to obtain complete sedimentation of fixed algal prior to enumeration. Br. Phycol. J. 17: 253–258.

Gayoso AM (1998) Long-term phytoplankton studies in the Bahía Blanca estuary, Argentina. ICES Journal of Marine Science 55: 655–660.

Goldsborough LG, Robinson GGC (1996) Pattern in wetlands, pp. 77–117 in Stevenson RJ, Bothwell ML, Lowe RL (Eds) (1996).

Hinton GCF, Maulood BK (1980) Some diatoms from brackish water habitats in southern Iraq. Nova Hedwigia 33: 475–486.

Hinton GCF, Maulood BK (1982) Contributions to the algal flora of Iraq: the non-diatom flora of the southern marshes. Nova Hedwigia 37: 49–63.

Huisman J, Matthijs HCP, Visser PM (2005) Harmful Cyanophyta. Dordrecht, The Netherlands: Springer Inc. (e-book).

John J (1993) The use of diatoms in monitoring the development of created wetlands at a sandmining site in western Australia. Hydrobiologica 269/270: 427–436, p. 222 as cited in Stevenson et al. (2006).

Mayer PM, Galatowitsch SM (1999) Diatom communities as ecological indicators of recovery in restored prairie wetlands. Wetlands 19: 765–774, p. 222 as cited in Stevenson et al. (2006).

Mitsch WJ, Gosselink JG (1993) Wetlands. 2nd ed. New York, USA: Van Nostrand-Reinhold.

Nurul-Islam AKM (1982) Marsh algae from southern Iraq. Int. Rev. Gesamt. Hydrobiol. 67(2): 245–60. Cited in Evans (2001).

Palmer JD (1996) Rubisco surprises in dinoflagellates. Plant Cell 8:343–345. Cited in Wehr JD, Sheath RG (2003).

Pankow H, Al-Saadi HA, Huq MF, Hadi RAM (1979) On the algal flora of the marshes near Qurnah (southern Iraq). Willdenowia 8(3):493–506.

Patrick R, Reimer CW (1975) The Diatoms of the United States. Vol. 2, Monograph No. 13. Philadelphia, USA: Academy of Natural Sciences.

Prescott GW (1944) How to Know the Freshwater Algae. Duduque, USA: Wm. C. Brown Company Publishers.

Prescott GW (1982) Algae of the Western Great Lakes Area. Dubuque, USA: Wm. C. Brown Publishers.

Rubec CDA, Bachmann A (2008) The Key Biodiversity Areas Program in Iraq: Objectives and Scope 2004–2008. Unpublished Project Report. Sulaimani, Kurdistan, Iraq: Nature Iraq

Seckbach J (2007) Algae and Cyanophyta in Extreme Environments. Dordrecht, The Netherlands: Springer Inc. (e-book).

Sivonen K, Jones GJ (1999) Cyanophytal toxins, pp. 41–111 in Chorus I, Bartam J (2005).

Smith GM (1950) The Freshwater Algae of the United States. New York, USA: McGraw-Hill Book Company.

Stevenson RJ, Bothwell ML, Lowe RL (1996) Algal Ecology: Freshwater Benthic Ecosystems. San Diego, USA: Academic Press.

Stevenson RJ, Pan Y, Kociolek JP, Kingston JC (Eds) (2006) Advances in Algal Biology: A Commemoration of the Work of Rex Lowe. Hydrobiologica 561: 221–238.

Stoermer EF, Smol JP (2004) The Diatoms Applications for the Environmental and Earth Sciences. Cambridge University Press. (e-book: netLibrary).

Thompson RH (1959) Algae. Cited in Edmonston WT (1959).

Ter Braak CJF, Šmilauer P (2002) CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (version 4.5). Ithaca, NY, USA: Microcomputer Power.

Wehr JD, Sheath RG (2003) Freshwater Algae of North America. San Diego, USA: Elsevier Inc.

Yaaqub A (1992) Algae of southern Iraqi marshes. Proceedings of the Forum on Southern Iraqi Marshes Environment. December 20–21, 1992. Basrah, Iraq. (In Arabic).

Appendix 1.

List of phytoplankton species identified during KBA-South Survey 2005–2007

CYANOPHYTA
- *Anabaena* sp.
- *Aphanocapsa* sp.
- *Aphanothece* sp.
- *Calothrix* sp.
- *Chroococcus dispersus*
- *Chroococcus limneticus*
- *Chroococcus minor*
- *Chroococcus minutus*
- *Chroococcus turgidus*
- *Chroococcus* sp.
- Coccoid algae
- *Gloeocapsa turgidus*
- *Gomphosphaeria aponina*
- *Leptolyngbya perelegans*
- *Lyngbya limnetica*
- *Merismopedia convolute*
- *Merismopedia glauca*
- *Microcystis aeruginosa*
- *Nostoc* sp.
- *Oscillatoria acuminata*
- *Oscillatoria amoena*
- *Oscillatoria amphibium*
- *Oscillatoria angustissimum*
- *Oscillatoria chalybeum*
- *Oscillatoria curviceps*
- *Oscillatoria earlei*
- *Oscillatoria geitleri*
- *Oscillatoria limnetica*
- *Oscillatoria limosa*
- *Oscillatoria minima*
- *Oscillatoria subberis*
- *Oscillatoria tenuis*
- *Oscillatoria tenuis* var. *natans*
- *Oscillatoria* sp.
- *Spirulina laxa*
- *Spirulina major*
- *Tolypothrix* sp.

EUGLENOPHYTA
- *Euglena acus*
- *Euglena convoluta*
- *Euglena minuta*
- *Euglena* sp.
- *Lepocinclis* sp.
- *Phacus gigas*
- *Phacus longicauda*
- *Phacus orbicularis*
- *Phacus* sp.
- *Trachelomonas* sp.

PYRROPHYTA
- *Dinobryon divergens*
- *Dinobryon sertularia*
- *Glenodinium quadridens*
- *Peridinium cinctum*

CRYPTOPHYTA
- *Chroomonas nordstedtii*
- *Actinastrum hantzschii*
- *Ankistrodesmus falcatus*

CHLOROPHYTA
- *Ankistrodesmus* sp.
- *Botryococcus braunii*
- *Botryococcus protuberans*
- *Botryococcus protuberans* var. *minor*
- *Botryococcus* sp.
- *Characium* sp.
- *Chlamydomonas* sp.
- *Closterium* sp.
- *Coelastrum astroideum*
- *Coelastrum microporum*
- *Coelastrum reticulatum*
- *Cosmarium formosulum*
- *Cosmarium hammeri*
- *Cosmarium setuiforme*

Cosmarium subcostatum
Cosmarium sp.
Crucigenia tetrapedia
Dictyospaerium sp.
Kirchneriella irregularis
Micractinium pusillum
Monoraphidium contortum
Monoraphidium convolutum
Monoraphidium sp.
Mougeotia sp.
Oedogonium cardiacum
Oedogonium sp.
Oocystis sp.
Ophiocytium bicuspidatum
Pandorina morum
Pediastrum boryanum
Pediastrum duplex
Pediastrum simplex
Pediastrum simplex var. *duodenium*
Pediastrum tetras
Pediastrum tetras var. *tetraodon*
Rhizoclonium sp.
Scenedesmus abundans
Scenedesmus acuminatus
Scenedesmus acuminatus var. *tetradesmoides*
Scenedesmus acutus
Scenedesmus arcuatus var. *platydiscus*
Scenedesmus bijuga
Scenedesmus bijuga var. *alternans*
Scenedesmus dimorphus
Scenedesmus quadricauda
Scenedesmus sp.
Schoederia antillarum
Spirogyra subsalsa
Spirogyra sp.
Staurastrum natator
Tetraedron caudatum
Tetraedron minimum
Tetraedron regulare
Treubaria setigera
Ulothrix sp.

BACILLARIOPHYTA

a-Centrales
Chaetoceros sp.
Coscinodiscus lacustris
Coscinodiscus sp.
Cyclotella atomus
Cyclotella kuetzingiana
Cyclotella meneghiniana
Cyclotella ocellata
Cyclotella radiosa
Cyclotella stelligera
Cyclotella striata
Stephanodiscus astrea

b- Pennales
Achnanthes affinis
Achnanthes biasolettiana
Achnanthes clevi
Achnanthes conspicua
Achnanthes hungarica
Achnanthes lanceolata
Achnanthes microcephala
Achnanthes minutissima
Achnanthes sp.
Amphiprora alata
Amphora coffeaeformis
Amphora ovalis
Amphora veneta
Amphora sp.
Aneumastus tusculus
Anomoeoneis exilis
Anomoeoneis sphaerophora
Bacillaria paxillifer (also known as *Bacillaria paradoxa*)
Brachysira exilis
Caloneis bacillum
Caloneis permagna
Caloneis silicula = *Caloneis ventricosa*
Campylodiscus clypeus
Cocconeis pediculus
Cocconeis placentula
Cocconeis placentula var. *euglypta*
Cocconeis placentula var. *lineata*

Cymatopleura solea
Cymbella affinis
Cymbella affinis var. *excisa*
Cymbella aspera
Cymbella cistula
Cymbella cistula var. *maculata*
Cymbella cymbiformis
Cymbella differta
Cymbella leptoceros
Cymbella microcephala
Cymbella parva
Cymbella prostrata
Cymbella pusilla
Cymbella sinuate
Cymbella tumida
Cymbella turgida
Cymbella ventricosa
Cymbella sp.
Denticula sp.
Diatoma elongatum
Diatoma elongatum var. *tenuis*
Diatoma tenue var. *elongatum*
Diatoma vulgare
Diploneis elliptica
Diploneis interrupta
Diploneis ovalis
Diploneis pseudoovalis
Diploneis sp.
Epithemia sorex
Epithemia turgida
Epithemia zebra
Epithemia zebra var. *porcellus*
Epithemia zebra var. *saxonica*
Eunotia formica
Eunotia pectinalis
Eunotia sp.
Fragilaria acus
Fragilaria acus var. *angustissima*
Fragilaria brevistriata
Fragilaria capitata
Fragilaria capucina
Fragilaria construens
Fragilaria pulchella
Fragilaria tabulata
Fragilaria ulna
Fragilaria ulna var. *biceps*
Fragilaria ulna var. *oxyrhynchus*
Fragilaria vaucheriae
Gomphoneis olivacea
Gomphonema acuminatum
Gomphonema angustatum
Gomphonema attenuatum
Gomphonema augar
Gomphonema constrictum var. *capitata*
Gomphonema gracile
Gomphonema gracile var. *turris*
Gomphonema intricatum
Gomphonema intricatum var. *pumila*
Gomphonema olivaceum
Gomphonema parvulum
Gomphonema sphaerophorum
Gomphonema tergestinum
Gomphonema turris
Gyrosigma acuminatum
Gyrosigma attenuatum
Gyrosigma macrum
Gyrosigma peisonis
Gyrosigma scalproides
Gyrosigma spencerii
Gyrosigma spencerii var. *nodifera*
Gyrosigma tenuirostrum
Gyrosigma sp.
Hantzschia amphioxys
Mastogloia braunii
Mastogloia elliptica
Mastogloia elliptica var. *dansei*
Mastogloia smithii
Mastogloia smithii var. *amphicephala*
Mastogloia smithii var. *lacustris*
Navicula anglica
Navicula atomus
Navicula bryophila
Navicula crucicula
Navicula cryptocephala
Navicula cryptocephala var. *intermedia*
Navicula cryptocephala var. *veneta*

Navicula cuspidata
Navicula gracilis
Navicula oblonga
Navicula parva
Navicula pseudotuscula
Navicula pupula
Navicula pygmaea
Navicula radiosa
Navicula radiosa var. *tenella*
Navicula rhynchocephala
Navicula similis
Navicula spicula
Navicula sp.
Neidium productum
Nitzschia acicularis
Nitzschia amphibia
Nitzschia angustata
Nitzschia angustata var. acuta
Nitzschia apiculata
Nitzschia clausii
Nitzschia commutata
Nitzschia cumutata
Nitzschia dissipata
Nitzschia fasciculata
Nitzschia filiformis
Nitzschia fonticola
Nitzschia frustulum
Nitzschia frustulum var. perminuta
Nitzschia gracilis
Nitzschia granulata
Nitzschia hungarica
Nitzschia inconspicua
Nitzschia intermedia
Nitzschia longissima
Nitzschia lorenziana
Nitzschia lorenziana var. *subtilis*
Nitzschia microcephala
Nitzschia obtusa
Nitzschia palea
Nitzschia punctata
Nitzschia punctata var. *coarctata*
Nitzschia romana
Nitzschia scalaris
Nitzschia sigma
Nitzschia sigma var. *rigidula*
Nitzschia sigmoidea
Nitzschia umbonata
Nitzschia tryblionella
Nitzschia tryblionella var. *levidensis*
Nitzschia tryblionella var. *victoriae*
Nitzschia umbonata
Pinnularia sp.
Plagiotropis lepidoptera
Pleurosigma angulatum
Pleurosigma elongatum
Pleurosigma obscurum
Pleurosigma salinarum
Pleurosigma sp.
Rhoicosphenia curvata
Rhopalodia gibba
Rhopalodia gibba var. *musculus*
Rhopalodia gibba var. *ventricosa*
Rhopalodia musculus
Rhopalodia parallela
Stauroneis phenicenteron
Stauroneis sp.
Surirella angustata
Surirella biseriata
Surirella capronii
Surirella ovalis
Surirella ovata
Surirella ovata var. *africana*
Surirella robusta
Tryblionella debilis

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RESEARCH ARTICLE

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Lichens of Israel: diversity, ecology, and distribution

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Abstract

The biota of lichen-forming and lichenicolous fungi of different plant-geographical regions of Israel was analyzed. These areas differ in climatic conditions. A total of 350 species from 16 orders, 52 families, and 117 genera were recorded; among them 5% are endemic to the Levant. The highest species richness was found in the Mediterranean area. Species diversity of other areas with more arid climatic conditions were much poorer in comparison with species diversity found in the more humid and cooler Mediterranean region. Saxicolous lichens were the most common species. However, in the Sudanian penetration area, terricolous lichens dominated. Among phytogeographic elements, temperate species were dominant. However, the Sudanian penetration area was characterized by the dominance of Mediterranean and subcontinental species. Most of the lichens studied were xerophytic and photophytic species. They dominated all plant-geographical areas of Israel. In the Mediterranean region, mesophytic lichens were also common.

Keywords

Ecology of lichens, lichen diversity, Israel, species composition

Introduction

The first lichens in the Mediterranean region were mentioned in the work of Müller Argo (1884). His paper included information on lichen species collected in the Negev desert. Later, lichenological investigations of this region were continued in the 1940s by I. Reichert, who published several papers on steppe and desert lichens (Reichert 1937a, b; 1940). He donated his unique lichen collection comprising specimens from Lebanon, Syria, Jordan, Egypt, and Israel along with his lichenological library to the Department of Botany, Tel Aviv University. The collection and library served as the basis for lichenological studies of Israel, which were continued by M. Galun and her students.

Among Reichert's students, the famous lichenologist Margalith Galun can be rightly considered as the founder of a new era in the history of Israeli lichenology. In 1958 she, together with Reichert, published her first paper about the lichen flora on olive trees (Reichert & Galun 1958). In the 1960s she started thorough floristic studies of all regions of the country. Her well known handbook, "The Lichens of Israel" (Galun 1970), was the first summary of lichen floristic explorations in Israel, which stimulated further lichenological investigations in the country. Her extensive studies including lichen diversity, lichen biology, lichen ecology, and lichen systematics during a period of 40 years extended the body of knowledge available in many fields of lichenology not only in Israel, but world-wide.

From 1969 until 1995, many scientists contributed to the knowledge of Israeli lichens. Among these contributions are the experimental works on photosynthetic and respiratory activity of desert lichens in the central Negev by the German scientist O. Lange and his colleagues (Lange et al. 1977). Lange also was engaged by the lichenometric studies in the Negev desert (Lange 1990). A number of interesting studies on the influence of air pollution on various characteristics (ecological, physiological, heavy metal content, etc.) of different lichen species were made by J. Garti and his students and colleagues. In the 1980s and 1990s, many investigations were devoted to the question of biogenous weathering of rocks by lichens. They were carried out by Danin and other scientists. On the basis of these studies, Danin proposed to use the patterns of biogenic weathering as indicators of paleoclimates in Israel (Danin 1985, 1986).

Since 1996, intensive lichenological investigations have been carried out by the Institute of Evolution, University of Haifa, in collaboration with colleagues from other institutes in Israel and abroad. These investigations are based on past achievements and continue up to the present time. They touch on the different fields of lichenology including lichen biodiversity, taxonomy, ecology, biochemistry, genetics, etc.

The present study represents a short review of lichens collected in Israel up to 2008. The following characteristics of lichen biota were studied: Systematics, species richness, species composition in different regions of Israel, phytogeographical elements, and ecological peculiarities.

Materials and methods

The paper is based on the results of expeditions to various regions of Israel from 2000 to 2007, and data collated from literature sources (Galun 1970, Galun & Mukhtar 1996, Temina et al. 2005). Lichen specimens were identified in the Laboratory of Lichenology at the Institute of Evolution, University of Haifa (Israel), applying standard methods. The following references were used to identify the specimens: Galun 1970, Clauzade & Roux 1985, Purvis et al. 1992, Wirth 1995, Boqueras 2000, and

Temina et al. 2005. Lichen nomenclature follows Temina et al. (2005). Specimens were deposited in the herbaria of the Institute of Evolution, University of Haifa, Israel. To estimate similarity between lichen vegetations of different regions, the Sørensen index (Mueller-Dombois & Ellenberg 1974) was calculated. To analyze local community organization, complexes of lichen species were subdivided into groups based on phytogeographical and ecological characteristics for each species according to Wirth (1995), Temina et al. (2005), and Nimis & Martellos (2008). The contribution of each group to the local lichen community was estimated on the basis of relative frequency (Mueller-Dombois & Ellenberg 1974).

Results and discussion

Species diversity

The biota of lichen-forming and lichenicolous fungi of Israel includes 350 species from 16 orders, 52 families, and 117 genera (Table 1). Among the various families, the highest species diversity is represented by the Teloschistaceae (55 species), Physciaceae (36 species), Lecanoraceae (28 species), and Verrucariaceae (26 species). The dominance of these families in species diversity shows a similarity of Israeli lichenobiota and lichenobiotas of the Mediterranean and Irano-Turanian regions.

Table 1. Systematic diversity of lichen-forming and lichenicolous fungi of Israel.

Order	Number of taxa		
	Family	**Genera**	**Species**
Agyriales	1	1	1
Arthoniales	3	8	24
Capnodiales	1	1	1
Dothideales	2	2	2
Lecanorales	20	53	175
Lichinales	4	10	23
Ostropales	3	3	10
Peltigerales	3	3	4
Pertusariales	1	2	8
Phyllachorales	1	1	1
Pleosporales	3	3	3
Pyrenulales	2	2	2
Teloschistales	2	5	56
Trichotheliales	1	1	3
Verrucariales	2	14	27
Order uncertan	3	4	6
Mitosporic fungi		4	4
Total	52	117	350

Species composition of different regions of Israel

Israel is climatically and geographically very variable as indicated by the presence of 29 geo-climatic regions (Rubin & Pick 1994). This extensive climatic variability results from the presence of the mesic/desert border and from the widening of the Saharo-Syrian aridity belt (especially during the Pleistocene and Holocene, Tchernov 1975). Four plant-geographical regions are represented in Israel (Zohary 1973): The Mediterranean, the Irano-Turanian, the Saharo-Arabian, and the Sudanian penetration (Fig. 1). The climate in these regions varies from mesic in the Mediterranean area to semi-arid in the Irano-Turanian area, to arid in the Saharo-Arabian area and to extremely arid in the Sudanian penetration area.

The largest number of lichens occurred in the Mediterranean area (Fig. 2), which is not surprising, as this area is ecologically more heterogeneous, represents a spatio-temporally "broader niche" (Van Valen 1965) and has more habitat patches and subdivisions than other regions of Israel. Analysis of the Sørensen Indices of Similarity (Table 2) showed significant similarity between lichen biota of the Saharo-Arabian and the Irano-

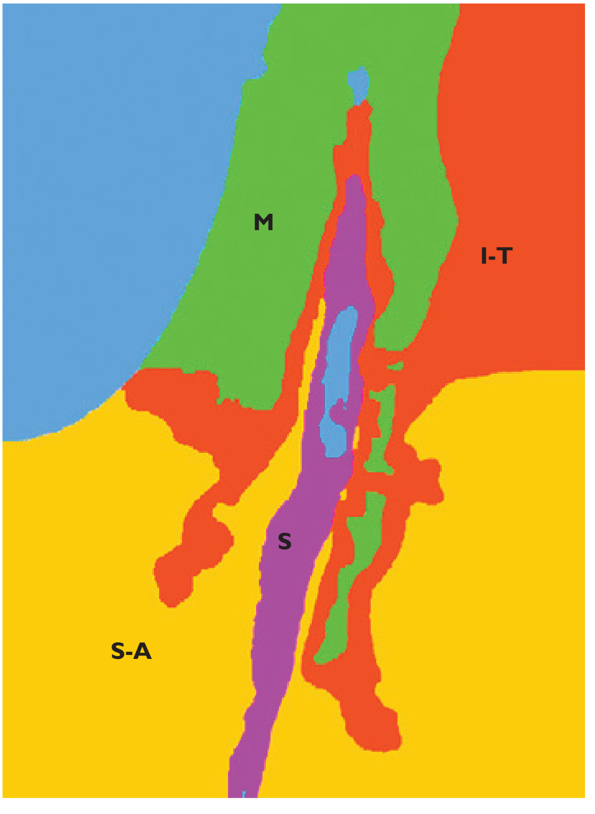

Figure 1. Plant-geographical regions of Israel. Abbreviations: **M** Mediterranean region **S-A** Saharo-Arabian region **I-T** Irano-Turanian region **S** Sudanian region.

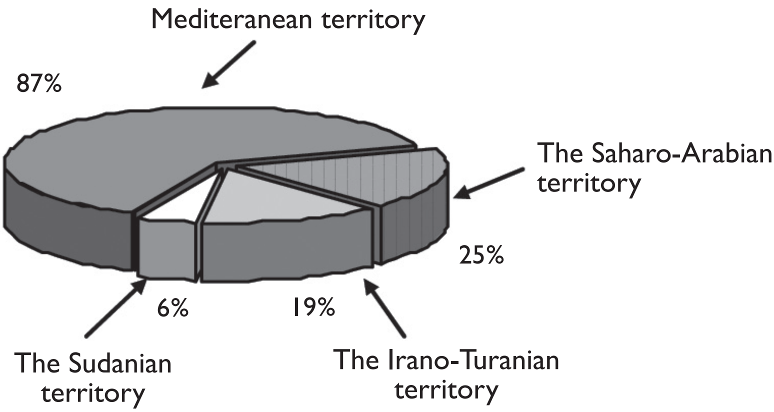

Figure 2. The species richness of lichens in different plant-geographical regions of Israel.

Turanian regions, apparently reflecting a relatively high degree of similarity of the climatic and biotic conditions of these regions. The frequencies of 60 basic species in the different plant-geographical regions are shown in Table 3. Only seven species were recorded in all regions. *Caloplaca aurantia, C. citrina, C. holocarpa, Placidium squamulosum*, *Psora decipiens,* and *Toninia sedifolia* are the most common lichens in Israel.

Substrates

Most lichens occurring in Israel are saxicolous species (Fig. 3A); among them, calcicolous lichens dominate. This may be attributed to the prevalence of limestone substrates in Israel. It is also possible to note the high presence of parasitic species in lichen biota. This is a characteristic feature of lichens of the Mediterranean region, which can perhaps be linked to the scarcity of free-living photobionts in this area.

The Mediterranean territory is characterized by the dominance of calcicolous and corticolous lichens (Fig. 3B). In the Irano-Turanian and Saharo-Arabian regions, calcicolous species prevail in lichen biota. The terricolous and substrate-indifferent lichens are the dominant species in the Sudanian penetration area, which probably reflects the lack of dew precipitation in this region.

Table 2. Sørensen index of similarity of lichen vegetation in different regions of Israel.

	Mediterranean region	Saharo-Arabian region	Irano-Turanian region
Saharo-Arabian region	26		
Irano-Turanian region	21	83	
Sudanian penetration region	3	26	16

Table 3. The frequencies of basic lichen species in different plant-geographical regions of Israel; (vr - very rare; r – rare; rc – rather common; c – common; vc – very common).

Species	Mediterranean region	Saharo-Arabian region	Irano-Turanian region	Sudanian penetration region
	Commonness-rarity status			
Acarospora areolata	-	c	rc	vr
Aspicilia desertorum	r	c	c	-
Aspicilia calcarea	c	r	r	-
Aspicilia farinosa	rc	rc	rc	-
Bacidina phacodes	rc	-	-	-
Bagliettoa parmigera	c	-	-	-
Buellia sorediosa	r	rc	r	-
Buellia subalbula var. *fuscocapitellata*	-	rc	r	-
Caloplaca alociza	rc	c	rc	-
Caloplaca arenaria	rc	r	rc	-
Caloplaca aurantia	vc	c	c	-
Caloplaca circumalbata var. *bicolor*	-	c	c	-
Caloplaca circumalbata var. *circumalbata*	-	vc	c	-
Caloplaca citrina	vc	c	c	-
Caloplaca erythrocarpa	c	r	-	-
Caloplaca holocarpa	vc	c	c	-
Caloplaca lactea	c	r	r	-
Caloplaca latzelii	rc	-	-	-
Caloplaca saxicola	rc	-	-	-
Caloplaca variabilis	c	r	r	-
Caloplaca velana var. *velana*	c	-	-	-
Candelariella minuta	-	c	c	-
Cladonia convoluta	c	-	-	-
Cladonia pocillum	c	-	-	-
Collema crispum	rc	rc	rc	r
Collema cristatum	c	vr	r	-
Collema tenax	c	rc	rc	r
Diploicia canescens	rc	r	-	-
Diploschistes candidissimus	rc	rc	rc	-
Diploschistes diacapsis	-	rc	c	-
Diplotomma epipolium	r	c	c	-
Diplotomma venustum	-	rc	rc	-
Lecania naegelii	c	-	-	-
Lecanora crenulata	r	rc	rc	-
Lecanora pruinosa	c	r	r	-
Lecidella euphorea	c	-	-	-

Species	**Mediterranean region**	**Saharo-Arabian region**	**Irano-Turanian region**	**Sudanian penetration region**
	Commonness-rarity status			
Lichinella sinaica	-	r	-	c
Lobothallia radiosa	c	-	-	-
Neofuscelia pulla	rc	-	-	-
Peltula obscurans	-	r	-	c
Peltula patellata.	-	r	-	c
Physcia adscendens	vc	-	-	-
Physconia venusta	rc	-	-	-
Placidium squamulosum	vc	c	c	r
Psora decipiens	c	c	c	r
Ramalina lacera	vc	-	r	-
Ramalina maciformis	vr	rc	rc	-
Rinodina bischoffii var. *aegyptiaca*	-	c	c	-
Rinodina dubyana	-	rc	r	-
Squamarina cartilaginea var. *cartilaginea*	vc	r	rc	-
Squamarina cartilaginea var. *pseudocrassa*	c	r	r	vr
Squamarina lentigera	vr	rc	c	vr
Teloschistes lacunosus	vr	rc	vc	-
Toninia sedifolia	c	rc	vc	vr
Tornabea scutellifera	rc	-	vr	-
Verrucaria fuscella	vc	-	-	-
Verrucaria marmorea	c	-	-	-
Xanthoria calcicola	rc	-	-	-
Xanthoria mediterranea	c	rc	rc	-
Xanthoria parietina	vc	r	r	-

Geographic distribution

Most lichens recorded in Israel are globally widely distributed and occur in all or almost all continents. However, about one-third of them are rare in the rest of the world; among them, 5% are endemic to the Levant. Lichens found in Israel belong to eight phytogeographical categories: temperate, northern temperate, southern temperate, sub-oceanic, Mediterranean, subcontinental, arid, and endemic. The temperate species dominate in the lichens of Israel. The other phytogeographical elements are much less common than the temperate species. Widespread temperate species prevail in the Mediterranean, Irano-Turanian, and Saharo-Arabian regions. The Sudanian penetration area is characterized by the dominance of Mediterranean and sub-continental lichens. The high abundances of endemic species in the Irano-Turanian and Saharo-Arabian regions are noteworthy.

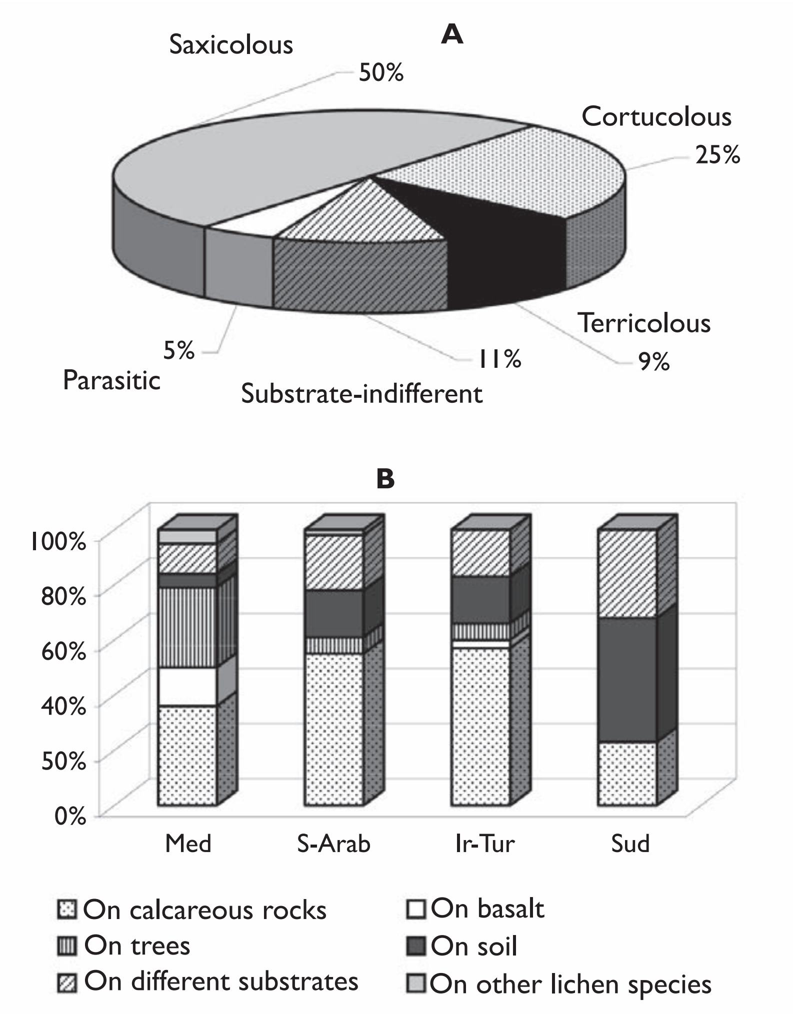

Figure 3. The frequencies of lichens on different substrates: A In all areas of Israel B in certain plant-geographical regions of Israel. Abbreviations: Med - Mediterranean region, S-Arab - Saharo-Arabian region, Ir-Tur - Irano-Turanian region, Sud - Sudanian region.

Ecology of the lichen species studied

The main factors influencing the distribution of lichens in arid areas are light and moisture conditions. As Fig. 4 shows, most lichens found in Israel represent xerophytic and photophytic species. The same groups of species dominate in all plant-geographical regions. However, in the Mediterranean region, high abundances of mesophytic and hygrophytic species were also observed. It is important to note that in this region the frequency of photophytic species is lower than the frequency of these species in other plant-geographical areas with higher solar radiation.

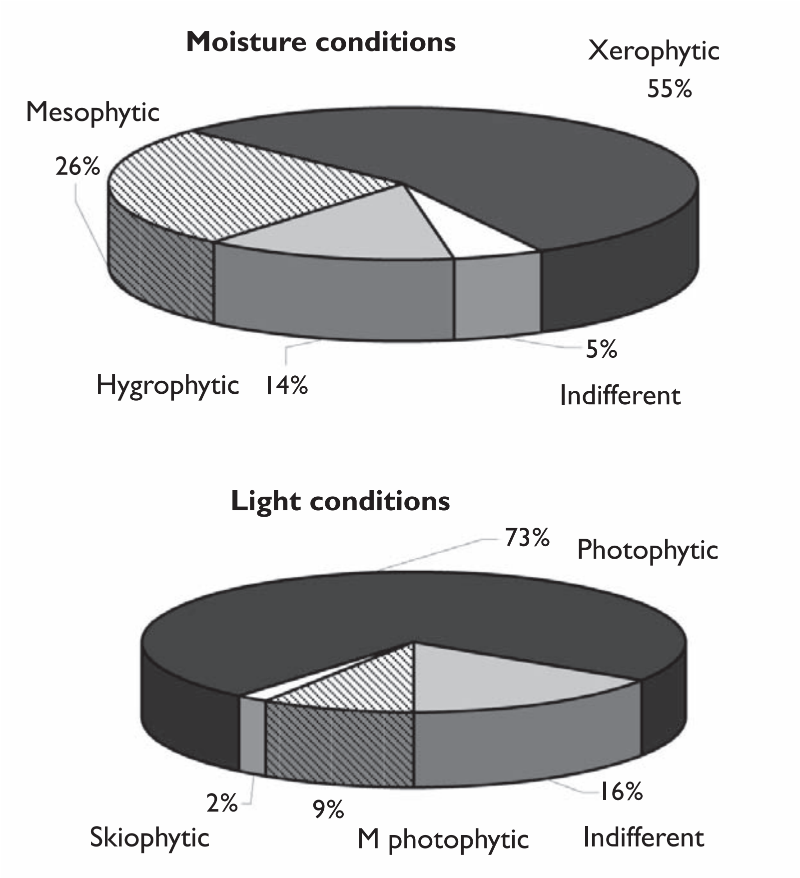

Figure 4. The ecological preferences of lichens found in Israel.

References

Boqueras M (2000) Líquens Epífits i Fongs Liquenícoles del Sud de Catalunya: Flora i Comunitats. Barcelona: Institut d'Estudis Catalans.

Clauzade G, Roux C (1985) Likenoj de Okcidenta Eūropo. Ilistrita Determinlibro. Bulletin de la Societe Botanique du Centre – Quest, Nouvelle Serie – Numero Special: 7, Royan, France.

Danin A (1985) Palaeoclimates in Israel: evidence from weathering patterns of stones in and near archaeological sites. *Bulletin of the American Schools of Oriental Research* 259: 33–43.

Danin A (1986) Patterns of biogenic weathering as indicators of palaeoclimates in Israel. *Proceedings of the Royal Society of Edinburgh* 89B: 253.

Galun M (1970) The Lichens of Israel. Jerusalem.

Galun M, Mukhtar A (1996) Checklist of the lichens of Israel. *Bocconea* 6: 149–171.

Lange OL (1990) Twenty-three years of growth measurements on the crustose lichen *Caloplaca aurantia* in the central Negev Desert. *Israel Journal of Botany* 39: 383–394.

Lange OL, Geiger IL, Schulze ED (1977) Ecophysiological investigations on lichens of the Negev Desert. V. A model to stimulate net photosynthesis and respiration of *Ramalina maciformis. Öecologia* 28: 247–259.

Mueller-Dombois D, Ellenberg H (1974) Aims and Methods of Vegetation Ecology. New York: J. Wiley & Sons.

Müller J (1884) Lichens de Palestine. Lichenes Palaestinenses s. Enumeratio lichenum a cl. et amic. W. Barbey-Bossier anno 1880 in Palaestina lectorum. *Revue Mycologique* 6: 12–15.

Nimis PL, Martellos S. ITALIC: The Information System on Italian Lichens. Version 4.0. University of Trieste, Dept. of Biology, IN4.0/1, 2008. [http://dbiodbs.univ.trieste.it/].

Purvis OW, Coppins BJ, Hawksworth DL, James PW, Moore DM (1992). The Lichen Flora of Great Britain and Ireland. London: Natural History Museum Publications & British Lichen Society.

Reichert I (1937a) Steppe and desert in the light of lichen vegetation. *Proceedings of the Linnean Society of London* 149: 19–23.

Reichert I (1937b) Eine lichenologische Skizze Palästinas. *Verhandlungen der Kaiserlich-Königlichen Zoologisch-Botanischen Gesellschaft in Wien* 86–87: 288–296.

Reichert I (1940) A new species of *Diploschistes* from oriental steppes and its phytogeographical significance. *Palestine Journal of Botany, Rehovot Series* 3: 162–182.

Reichert I, Galun M (1958) Some lichens on olive trees in Israel. *Bulletin of the Research Council of Israel* 6: 237–244.

Rubin S, Pick K (1994) Climatic data for heating and cooling systems in Samaria. *Judea Samaria Res. Studies* 3: 353–369.

Tchernov E (1975) Rodent fauna and environmental changes in the Pleistocene of Israel. In Prakash I, Ghosh DK (eds.) Rodents in desert Environments. The Hague: Dr. W. Junk Publ.

Temina M, Kondratyuk SY, Zelenko SD, Wasser SP, Nevo E (2005) Lichen-forming, lichenicolous and allied fungi of Israel. Ruggell: A.R.A. Ganter Verlag K.-G.

Van Valen L (1965) Morphological variation and width of ecological niche. *Amer Nat* 99: 377–390.

Wirth V (1995) Die Flechten Baden-Württembergs. Teil 1 & 2. Stuttgart: Eugen Ulmer GmbH & Co.

Zohary M (1973) Geobotanical Foundations of the Middle East. Gustav Fisher Verlag, Stuttgart.

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RESEARCH ARTICLE

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Complex *ex situ* - *in situ* approach for conservation of endangered plant species and its application to *Iris atrofusca* of the Northern Negev

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Abstract
We introduce a novel approach for conservation of endangered plant species in which *ex situ* collections maintained in natural or semi-natural environment are a part of a complementary *ex situ – in situ* conservation strategy. We provide detailed guidelines for 1) representative sampling of the populations; 2) collection maintenance; and 3) utilization for *in situ* actions. Our approach is the first that explicitly takes into account ecologically significant (i.e. adaptive) variation of plants in both *ex situ* and *in situ* conservation actions. We propose that an important part of the conservation strategy is preserving both neutral and adaptive genetic diversity through a quasi *in situ* conservation approach. Finally, we demonstrate this approach using a critically endangered plant species, *Iris atrofusca* from the northern Negev, Israel.

Keywords
In situ, *ex situ*, conservation strategy, relocation, translocation, local adaptation

Introduction

A large body of theoretical and empirical work has been devoted to particular questions about optimal conservation, such as the importance of inbreeding depression (Hedrick and Kalinowski 2000, Keller and Waller 2002), population size (Barrett and Kohn

1991, Ellstrand and Elam 1993), isolation (Newman and Tallmon 2001), genetic diversity (Lande and Barrowclough 1987; Newman and Pilson 1997) and outbreeding depression (Hufford and Mazer 2003, Tallmon et al. 2004). But, to-date there were limited attempts to conceptually unite different aspects of population viability as part of a conservation methodology. Such unification is especially lacking for *ex situ* conservation. In this paper we review the state-of-art in *ex situ* conservation with an emphasis on its utilization within a more general strategy having a final *in situ* output. Then we introduce a detailed approach for conservation of endangered species that integrates *ex situ* and *in situ* conservation as complementary and that could be used as a tool for finding an efficient solution to a particular conservation task. Finally, we present a study where this approach is applied for an endangered plant species.

Ex situ conservation

Ex situ conservation methods samples genetic diversity of species using certain criteria and store/propagate the collected material outside the natural environments in which the species grows (Heywood and Iriondo 2003). Importance of *ex situ* collections for conservation in situ was realized when collections in botanical gardens and arboreta helped implementation of population management and recreation (Falk 1987; Given 1987; Millar and Libby 1991). At the same time, limitations of their usefulness became evident. The latter include poor genetic or demographic management almost inevitably resulting in genetic erosion, artificial selection and spontaneous hybridization. To prevent/reduce negative effects of genetic drift, inbreeding depression and mutational meltdown, that all happen as a result of small (effective) population size of a collection, sampled individuals must be maintained separately or through controlled breeding and pedigree design. This introduces other limitations of *ex situ* collections, such as space limitations and high cost of maintenance.

A need of a conceptually sound link between conservation-oriented ecological and genetic research, and its routine application to *ex situ* management has been recognized (Maunder et al. 2004a). *Ex situ* conservation needs biologically effective, financially realistic and easy-to-use guidelines that can be applied to a wide range of situations. The development of such guidelines must take into consideration basic issues of conservation biology. Traditionally, the germplasm sampled for *ex situ* collection is supposed to represent potential adaptive variation within a species (Brown and Briggs 1991, Brown and Marshall 1995, von Bothmer and Selberg 1995). In case of limited resources for collecting and maintaining plants, minimal sampling can precede additional sampling, which will be performed upon availability of more resources (Brown and Briggs 1991). The key issue is choosing a limited, but representative, number of populations, using the correct criterion. This criterion, in our view, should be ecologically significant (i.e. not the potentially adaptive, but the currently adaptive) variation. Therefore, research that allows detection of spatial pattern of morphological, life history and fitness traits, should be the first priority tool for providing sampling guidelines (Husband and Campbell 2004). Although variation revealed with molecular markers can provide valuable insights into the importance of different non-selective processes in species evolution, this information is secondary for making conservation decisions.

An endangered species is usually represented by small and isolated populations that already underwent strong effects of genetic drift and/or inbreeding, i.e. comprise a limited number of genetically different individuals (Aguilar et al. 2008). Open pollination in a sample from such a population may result in inbreeding depression due to high probability of mating between genetically identical or closely related genotypes. On the other hand, interbreeding of individuals from environmentally dissimilar habitats planted in close proximity often leads to outbreeding depression. These two risks rarely apply to obligate or predominant selfers, but can be extremely important for outcrossing, and especially for self-incompatible species. Outbreeding depression is an opposite, as compared with beneficial gene flow between genetically differentiated (isolated) populations, hybridization process. The parents do not necessarily have to be taxonomically distinct, viz. be recognized as different subspecies. Therefore, for an endangered species, creation of *ex situ* collections and decisions about suitable material for relocation/reintroduction should take into account the potential risks of inbreeding/outbreeding depression, in addition to local adaptation and spatial structuring of adaptive variation.

The above issues should be considered as the basic principles in developing an *ex situ* conservation approach that would be an integral part of a more general strategy with an ultimate final *in situ* output. Several approaches combining *ex*- and *in situ* conservation were proposed in the past, but none is satisfying as a general conservation strategy. For instance, the *inter-situ* approach proposes an off-site collection maintained within the natural habitat. This approach was considered potentially promising, but was not tested and no detailed methodology for practical use was developed (Husband and Campbell 2004). A slightly different approach are the "forest gene banks" (Uma Shaanker and Ganeshaiah 1997, Uma Shaanker et al. 2001, 2002). In this concept, a particular existing population acts as an *in situ* sink, into which genetic material from several source sites is introduced and maintained. Thus the genetically diverse sink population serves as a repository of the species gene pool and at the same time allows for random interbreeding. This approach might be useful in certain cases (lack of local adaptation, low genetic diversity, self-incompatability), but may lead to outbreeding depression when locally adapted genotypes are brought together. Therefore this concept cannot be used in a general application.

"*Quasi in situ*" conservation

Here, we propose the use of *ex situ* collections in natural or semi-natural environments as a part of a complex *ex situ – in situ* conservation strategy. Here below we provide detailed guidelines for 1) representative sampling; 2) collection maintenance; and 3) utilization for *in situ* conservation actions. The novelty of our approach is in that it explicitly takes into account potential local adaptation of plants in both *ex situ* and *in situ* conservation actions. An integral part of this strategy is preserving the species genetic diversity (both neutral and adaptive) through "*quasi in situ*" conservation.

The proposed strategy starts with an analysis of the species distribution to identify potential locally adapted populations or population groups. This analysis is crucial for understanding the extent of local adaptation and its spatial pattern. As intensity of local selection varies, either gradually with increase in distance or abruptly with change in a habitat, only knowledge of the local selection regimes can tell us whether material is adapted or not. Two main procedures exist to identify local adaptation: transplantation experiments (e.g. Joshi et al. 2001, Volis et al. 2002), and tests for outbreeding depression, when a locally adapted genotype is crossed with plants originating from elsewhere (Hufford and Mazer 2003). If local adaptation is important, the introduced genotypes must fit into the local biotic and abiotic conditions, i.e., it should come from within the area defined as that of intensive local selection, or from a habitat with closely similar local selection effects.

Experimental determination of a scale of local adaptation (Fig. 1) is a highly desired second step of the procedure. A potential for local adaptation and its spatial scale can be roughly predicted from knowledge of a species' breeding structure and life history. Self-pollination and short seed or pollen dispersal distance are known to be associated with a smaller scale of local adaptation than outcrossing and long-distance seed or pollen dispersal (Linhart and Grant 1996). However, these considerations are too general to

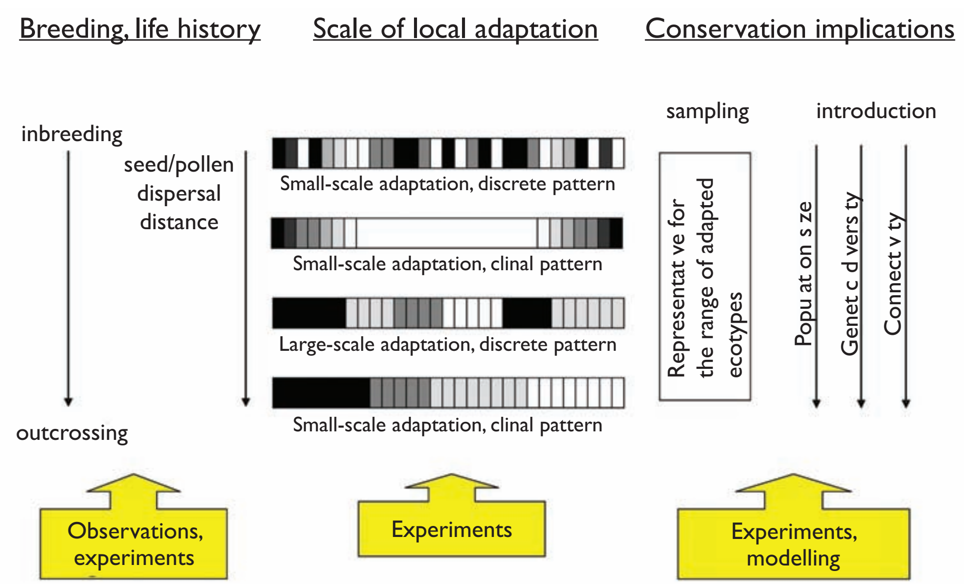

Figure 1. A scheme of relationship between (i) species properties (breeding structure, life history) and (ii) scale of local adaptation, and implications of (i) and (ii) for sampling and introduction. The scheme shows that predominant outcrossing and large dispersal distance are associated with large scale local adaptation, necessitating increased size, genetic diversity and connectivity of introduced populations.

be used as guidelines for conservation of a particular species because of numerous other factors, such as patterns of environmental variation (e.g. discrete or clinal), number of available habitats, a species' evolutionary potential, time since the last colonization, etc. Therefore, an experimental assessment of the scale of local adaptation is crucial. Such a test should include all habitats where the species is found (discrete variation) or locations along an environmental gradient (clinal variation). Of course, logistical considerations may limit a range of habitats or locations to be tested, or prevent testing for local adaptation at all. In this case variability in morphology, phenology and life history traits across a species' range must be known. This variability matching important environmental parameters (e.g. temperature, soil type, rainfall) or being associated with distinct habitats or vegetation communities are indications of local adaptation.

If phenotypic or genetic variation is spatially structured, even though it is not a result of natural selection, it may represent distinct evolutionary lineages within species, being an important part of the species' diversity. This variation, although neutral, is important for preserving species evolutionary potential, i.e. ability to adapt to future climate or habitat changes. As neutral genetic variation in many cases is not reflected in phenotypic or in molecular markers variation, its existence must be presumed when a species consists of populations not connected through gene flow.

With knowledge about spatially structured adaptive and neutral variation, a sampling design is worked out. The optimal design for *ex situ* collection is a stratified one, with a lower level (of neutral variation) nested within a higher one (of adaptive variation). Practically, this means that for a species present in several habitats (e.g. soil types, regions of different aridity, vegetation communities), sampling in each habitat must include several geographically isolated populations. A representative number of spatially separated individuals must be collected in each population, to ensure sampling of different genotypes.

The next step is planting the germplasm sampled as living collection. In the *quasi in situ* approach, a choice of a site must take into account local adaptation (tested or presumed). This means that there must be a close environmental match of *ex situ* location with locations of sampled natural populations. A close match can be biologically meaningful only if the *ex situ* location is in a natural (or at least semi-natural) environment. In addition, this site should be protected by national law and practically (regularly) inspected by rangers. In our view, different classes of strictly protected territories are the areas that fully satisfy these requirements. An optimal design would be planting several populations representing a particular eco-geographical region or habitat in a protected area in the same eco-geographical region or habitat. A representative number of genetically different individuals per population should be planted separately at distances, allowing subsequent identification of planted genotypes. This is important for both estimating rate of survival and enabling controlled pollination, if necessary. Following the recommendations of the Center for Plant Conservation in the United States (Maunder et al. 2004a), number of plants per population should be 10 to 50, and five populations per habitat or eco-region should be sampled.

A comparison between *quasi in situ* and traditional *ex situ* conservation in botanical gardens is summarized in Table 1. We argue that the *quasi in situ* approach provides better representation of genetic diversity, increases chances of germplasm survival, and better suits the purpose of propagating material for *in situ* conservation actions.

In situ conservation aims at either enhancement of existing populations or creation of self-supported new populations via reintroductions and translocations, using sampled or propagated material (reviewed in Bottin et al. 2007, Menges 2008). When a natural population exists, or existed in the recent past, a choice of material is quite straightforward. A large population from the same or the geographically closest population within the same habitat would be the best choice. If, however, relocation is planned, viz. introduction of material into locations where a population never existed, a decision is more problematic. There are many examples of unsuccessful relocation into sites that seemed highly suitable and were located in close proximity to a location where natural populations had been extirpated (e.g. Holland 1980, Morton 1982, Cranston and Valentine 1983). This implies that the recommendation by Schaal and Leverich (2004) to use for relocation a large sample from the closest population representing the same habitat, should be treated with caution and only applied when data on a species' environmental requirements are very limited. A much better option is a limited relocation within an experimental framework, and a full relocation in those sites where survival and reproduction are high.

As soon as the relocation sites are chosen, material for propagation may be taken from natural or *ex situ* collections. The major issues are required origin, genetic diversity and quantity. Acquiring sufficient quantity of propagation material (seeds, bulbs, root cuttings, saplings) from the closest natural population can negatively affect the latter's growth rate and threaten its viability. In addition, single source material may lead to inbreeding depression and high susceptibility to diseases. *Quasi in situ* collection may effectively solve both problems. Plants, grown in the collection, are (presumably) locally adapted and genetically different as they originate from several populations. Additionally, naturally occurring cross-pollination of plants in a collection should neither lead to breakdown of co-adapted gene complexes, nor to dilution of local adaptation because all plants in the collection originated from the same environment and no maladapted genes will participate in recombination and segregation. Therefore, the offspring of cross-pollination in a collection should well suit the relocation purpose, and can be collected in large quantities to meet the needs for successful relocation.

The last step in the *quasi in situ* strategy is determination of spatial parameters of introduced populations (size, distance from the nearest population) and monitoring of relocation success. Again, as with choosing a relocation site, experimentation should

Table 1. A comparison between *quasi in situ* and *ex situ* conservation.

Parameter	Ex situ	Quasi in situ
Space for maintaining the collection	Limited	Less limited
Suitability of environment	Usually un-suitable	Suitable
Maintenance and renewal of material	Artificial	Natural
Cost	High	Very low and only at the initial stage

be a common practice when several populations of different size are planted and monitored over a number of years.

Application: *Iris atrofusca* of the northern Negev as a case study

Iris atrofusca Baker (Fig. 2) belongs to the section *Oncocyclus* (Siems.) Baker (Iridaceae) that are characterized by dense clonal growth and conspicuous large, mostly dark flowers that grow individually on a stem (Avishai and Zohary 1980, Sapir et al. 2002). Eight species of *Oncocyclus* that grow in Israel (Feinbrun-Dothan 1986, Danin 2004) have high conservation priority (Sapir et al. 2003) and are included in the Red Data Book of the country (Shmida and Pollak 2007). *Iris atrofusca* is one of the most threatened species of *Oncocyclus* irises in Israel these days (Shmida and Pollak 2007).

Iris atrofusca is relatively widely distributed. It occurs from the northern Negev in the south to the Golan heights in the north. This distribution is the widest of all *Oncocyclus* species in Israel. Identification is not always easy. Sapir et al. (2002) showed that morphologically it does not differ from its closest relatives, *I. haynei* and *I. petrana*. Morphological traits are also associated with the aridity gradient (Arafeh et al. 2002, Sapir et al. 2002). However, morphological and genetic analyses indicated that *I. atrofusca*

Figure 2. Leaf fans, flowers and rhizomes of *Iris atrofusca* from the Goral Hills, northern Negev (watercolor by Irene Blecher © 2006).

populations of the northern Negev form a cluster within the general pattern (Arafeh et al. 2002, Sapir et al. 2002), and might even represent a separate taxon (Kushnir 1949).

The habitats of *I. atrofusca* in the northern Negev are the most vulnerable throughout its distribution. In the last decade, *I. atrofusca* populations of the northern Negev have been suffering mainly from anthropogenic disturbance that decreased population sizes, with some populations becoming extinct. These disturbances include urbanization, infrastructure works, intensive and extensive agriculture, overgrazing, forestry works, and illegal Bedouin settlements. Recently, a plan for expanding the area of Beer Sheva, the main town of the northern Negev, is threatening the largest and the densest populations of *I. atrofusca*, which grow in Goral Hills, north of the town. These issues lead to urgent research of *I. atrofusca* populations in the Negev. Here we present studies we did under the guidelines we drew above for the *quasi in situ* conservation approach.

Methods

Research area

Iris atrofusca grows in the northern Negev in two main groups of populations: in Goral Hills (central coordinates: 31°18'N 34°48'E), north to Beer Sheva, and Arad Valley (central coordinates: 31°16'N 35°07'E) (Shimshi 1979/8).

The two regions differ in climate. While the Goral Hills area is above the 200 mm isohyet (semi-arid conditions), the Arad Valley is close or below to the 150 mm isohyet, which indicates arid conditions (Atlas of Israel 1985, Jaffe 1988).

The topography of the Goral Hills area is mostly slopes of shallow hills. The angles of the slopes are up to 20%. The soil is a shallow calcareous lithosol overlying fractured Eocene limestone (Shimshi 1979/80). Depressions between the hills are filled with shallow loessial soil. Arad Valley, on the other hand, is a relatively flat plain (with wadis and gullies), covered with Quaternary aeolian loess of considerable thickness (> 2 m), with some isolated outcrops of calcareous lithosols (Shimshi 1979/80), which are mostly the heads of insulated hills.

In hard and fissured limestone and dolomite with calcareous lithosol some of the rain water penetrates the soil and is accumulated in the fissures and crevices, where it is protected from direct evaporation. Loessial soils have a different moisture regime. Due to the high moisture holding capacity of the fine-grained substratum, some of therain water is absorbed by the upper soil layers, but most of this water is consequently lost by direct evaporation from the soil surface (Danin 1988).

Inventory and demographic observations

A field survey based on previous knowledge on the distribution of the species in the northern Negev was conducted in 2006. The survey aimed at documenting the precise locations of populations, the distributing area of each population, and to record ecological conditions and anthropogenic impacts. In each population, clumps of *Iris atrofusca* were recorded for their size, estimated by the diameter of the clump.

To assess population growth rates, we started, in 2006, a detailed census of two populations representative of two regions, the Goral Hills and Arad Valley (Gvaot Goral, G-G, and Tel Arad, T-A, respectively) (Fig. 3). Two permanent observation plots were established: 120 m x 6 m (G-G) and 60 m x 6 m (T-A), respectively). In March 2006 we counted all individuals within the plots and classified them as either immatures (1st or 2nd year juveniles with a single fan), vegetative (non-flowering, but with > 1 fan) adults or reproductive adults (Fig. 4). We marked each established clump (=genet) of *I. atrofusca* individually, measured its diameter and counted the number of leaf-fans (=ramets). Also in April 2007 and 2008, we recorded number, size, and reproductive status of adults in the plots. Each season (2006, 2007 and 2008) we calculated the average number of fruits per reproducing plant (i.e. a clump comprising >1 ramets), average number of seeds per fruit, and resulting fecundity. Measurements and counting were done when plants started to senesce.

Since the actual age of individual plants of *I. atrofusca* in the field can not be determined, the population structure analysis was based on the number of individuals

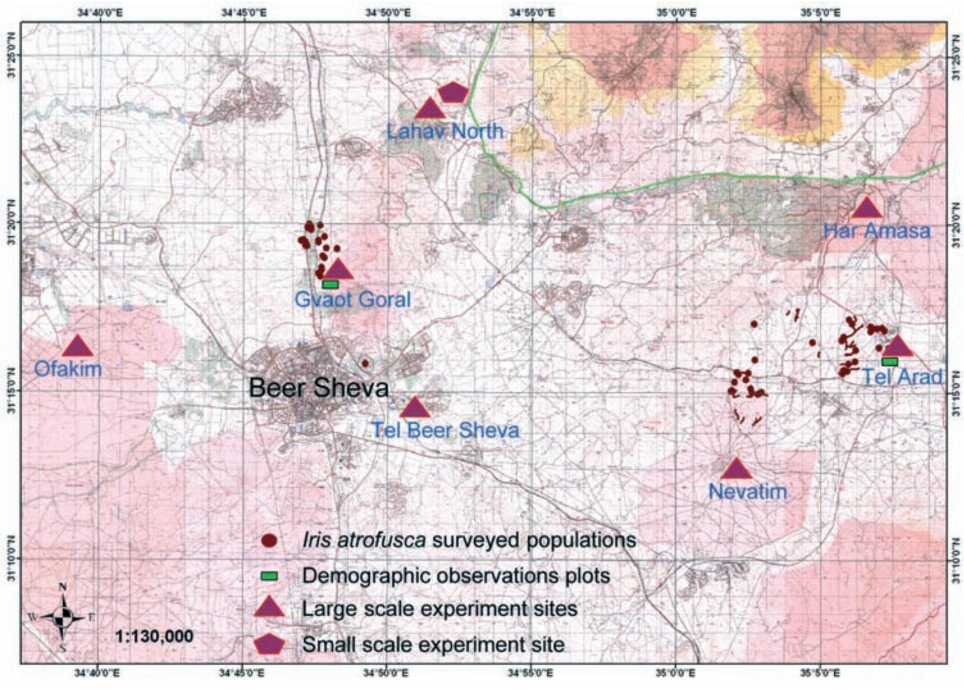

Figure 3. Map of populations surveyed, experimental relocation sites and populations in which permanent demographic observations plots were established.

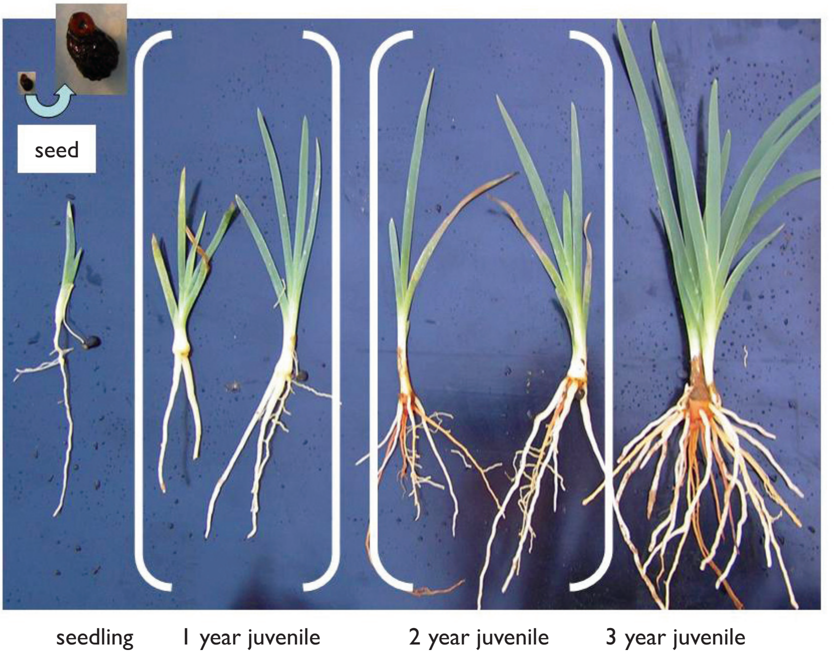

Figure 4. Plants of *I. atrofusca* followed from seed germination on and representing different age-stages (seed, seedling, juvenile and vegetative adult).

in the different ontogenetic stages of the life cycle. During the years 2005 to 2008 we followed the germinated seeds to distinguish age-stages in *I. atrofusca*. We identified the following age-stage categories (Fig. 4):

1. Seeds;
2. Seedlings (individuals developed shortly after germination of seeds, with cotyledons and often with one pair of leaves);
3. Juveniles (individuals with a single leaf fan comprising more than two leaves and having a poorly developed root system); a major difference between 1-year and 2-year juveniles is in the development of the root system, where the latter starts to develop a rhizome;
4. Vegetative adults or immatures (non-flowering individuals with more than two leaf fans and fully developed root system, which has a developed rhizome);
5. Generative adults (individuals bearing flowers).

Oncocyclus plants are dormant between the end of the flowering season (end of spring) and the start of the next winter. Our observations indicate that plants can stay dormant during not only summer, but also during the next growing season, from fall to spring (Volis & Blecher, pers. obs.). This adds another ontogenetic stage for adults – dormants, which will be verified as more demographic data become available.

Adult plants can be distinguished from juveniles in the field by the compact assemblage of leaf fans, which emerge close to each other from the below-ground rhizome (Fig. 4). All these leaf fans are genetically identical individuals (ramets) that may become independent plants after fragmentation of the mother rhizome (genet).

Plant sizes and number of fans per clump were log-transformed and analyzed across years and habitats using repeated-measures ANOVA. Only alive and non-dormant adults were analyzed for these two traits.

Soil seed-bank and germination trials

We created three experimental permanent soil seed banks and started monitoring the fate of the seeds in fall 2005 at Tel Arad National Park (Fig. 3). Seeds of *I. atrofusca* were collected by MB from plants in proximity to the plots under observation in 2005. The seeds were buried at three sites along the slope in: (1) plastic trays filled with soil of the site of transplanting and containing one spikelet per cell (221 seeds per tray, one tray per site), placed about 2 cm below ground level, and (2) in furrows (100 seeds per furrow, two furrows per site).

Similar soil seed banks were established in fall 2006 at Gvaot Goral site (Fig. 3). Two trays, each containing 221 locally collected seeds, were buried at the top and the bottom of the hill. The experimental soil seed banks were monitored for seed germination during 2006 to 2008.

Effect of rhizome initial size on growth and flowering

This experiment was conducted during the growing seasons of 2005 and 2006. We used only rhizomes with one distinct bud to test the effect of initial rhizome weight on probability of flowering. We also measured several morphological traits to identify potential morphological indicators for probability of flowering. Rhizomes were planted in 3-liter pots filled with loess soil, one weighted rhizome per pot. Pots were placed 25 cm apart in a nethouse, and watered regularly with 2-liter/hour drippers, one dripper in each pot. During the experiment (November – April) plants were getting natural rainfall (208 mm) plus supplementary watering (equivalent to 95 mm of rainfall), to compensate for the higher evaporation rates from the pots. At first sign of leaves senescence the following measures were taken: length and width of the longest leaf, diameter at the base of the leaf fan, number of ramets, and number of flowers. After complete drying out of above-ground biomass the rhizomes were dug out and weighted. The sample size was 204 plants. Large rhizomes rescued by MB in 2005 from the Goral Hills (road-building strip for new railroad tracks) that represented a group of (potentially) independent ramets were cut into pieces and used in this and the following experiments.

Creation of quasi in situ gene banks

Between 20 to 50 large genets of *I. atrofusca*, comprising many ramets, were sampled from four populations from Goral Hills and Arad Valley regions. Populations were chosen based on: (1) the threat of habitat destruction – the populations chosen were critically endangered (construction, agriculture, etc.) and required immediate relocation; and (2) their representation for the distributional range of *I. atrofusca* in the northern Negev. The plants were planted in two replicates at both Tel Beer Sheva and Tel Arad National Parks (Fig. 3) that represent ecological conditions like those of Goral Hills and Arad Valley areas, respectively. However, as the two population groups (Goral and Arad areas) were found to differ in habitat, demography and morphology (Shimshi 1979/80; Blecher 2007 and this study), we decided that Tel Beer Sheva and Tel Arad National Parks will harbor populations from their respective regions only, and the populations planted outside their region of origin will be relocated to the refuge in their respective region at the next stage of the project. Meanwhile, we are monitoring the transplanting success of plants of different origin across the two regions.

Relocation experiments

Rapid disappearance of *I. atrofusca* populations in the Negev necessitates measures of species conservation, such as relocation to safe areas, protected by law. In order to determine species' habitat preferences we set relocation experiments at two scales, large (tens of kilometers) and small (hundreds of meters), respectively, using rhizomes rescued from sites of habitat destruction and immediate threat for the plants, i.e. from populations that required relocation.

Large scale relocation experiment

Two sets of five large (> 20 g) and 15 small (5–10 g) rhizomes of *I. atrofusca* of Arad Valley and Goral Hills origin were planted in six locations that embraced the whole species range in the Negev and beyond it. The locations were: KKL experimental site near Ofakim, Tel Beer Sheva National Park, Nevatim Basis, Lahav North Nature Reserve, Tel Arad National Park, Har Amasa Nature Reserve (Fig. 3). In spring 2007 and 2008 we recorded the numbers of surviving plants, flowers and fruits per plant.

Small scale relocation experiment

Rhizomes rescued in spring 2006 in the Goral Hills area (construction of new railroad tracks) were planted in fall 2006 in sets of 62 rhizomes at 22 microhabitats in Lahav

North Reserve (Fig. 3, 9). Each set comprised the following size classes: <5 g (14), 5–10 g (10), 10–20 g (23), 20–30 g (10), 30–40 g (3) and >40 g (2). In spring 2007 and 2008 we recorded the numbers of surviving plants, flowers and fruits per plant.

Results

Distribution and habitats

The results of this survey (Table 2) clearly show that in the Arad Valley about a third of the plants of *I. atrofusca* grow in wadis. In the Goral Hills area, no population was found in wadis. Detailed geographical interpretation of data on *I. atrofusca* survey in the northern Negev, including categorization of the populations for protection purposes, is presented in Blecher (2007) with proposals for new protected areas and enlargement of the existent Parks.

The two populations studied (Gvaot Goral and Tel Arad) differed in average plant density, estimated in spring 2006 (0.88 vs. 0.30 plants/m^2 in G-G and T-A, respectively). There was a marginally significant difference between two populations in clump size, with clumps at G-G being consistently larger during three years than at T-A. The number of ramets per genet exhibited significant season/population interaction. This trait was more constant over the years at G-G than at T-A (Table 3).

The two populations differed in the stage structure, with juveniles comprising 86%, 70% and 46% vs. 23%, 24% and 20% of established plants (over three years) in G-G and T-A populations, respectively (Table 4). Percentage of flowering adults and average fruit-set per reproducing plant over three years were higher in G-G than in T-A population (40±13% vs. 67±10% and 1.61±0.38% vs. 0.52±0.30%, respectively). The two populations also dramatically differed in fecundity (Table 4).

Germination

Low germination rates were observed in the soil seed banks established in 2005 at Tel Arad National Park. During three seasons, 2005–6, 2006–7 and 2007–8, no germination event was recorded in any of the buried trays with seeds. In furrows, no germination was observed in 2005–6 and 2006–7, but in 2007–8 germination fraction was

Table 2. Number of plants and distribution of *Iris atrofusca* in two geographic regions.

	Total distributing area (Hectare)	Total cover of plants* (m^2)	Total number of clumps	Hills and slopes	Wadis
Goral Hills	19.3	186	1968	1968	0
Arad Valley	34.8	439	4716	2931	1785

* Total cover of plants is a summary of all clumps.

4%, 15% and 12% (hill top, middle and foot, respectively) In the Gvaot Goral site, where 2 trays (experimental soil seed banks) were buried in fall 2006, one seed germinated in the following winter (season 2007–2008). These results suggest strong seed innate dormancy in the first year after dispersal with increase in germination fraction in following years.

Table 3. Repeated measures ANOVA of the effects of population and season on clump size and number of ramets per genet (top) and means ± S.E for each season (bottom). G-G – Gvaot Goral population, T-A – Tel Arad population.

Source of variation	**DF**	**F**	**F**	
		Clump size	Ramets per genet	
Population	1	2.91†	2.38 ns	
Error	109			
Season	2	0.59 ns	1.82 ns	
Season * Population	2	0.91 ns	6.15**	
Error	218			
Season	Clump size (cm)		Ramets per genet	
	G-G	T-A	G-G	T-A
2005–6	24.0±2.6	19.8±2.4	21.5±3.3	18.6±3.2
2006–7	23.1±2.6	19.8±2.5	18.3±2.5	15.0±2.5
2007–8	25.1±2.5	22.6±2.8	18.0±2.3	21.8±2.8

** $p < 0.01$; † $p < 0.10$; ns not significant.

Table 4. Life table for two populations of *I. atrofusca* during the seasons 2005–6, 2006–7 and 2007–8. The table does not account for soil seed bank present at the start of observations. Numbers are for the whole plot.

Population/stage	**Season**		
	2005–6	**2006–7**	**2007–8**
Gvaot Goral (G-G)			
Seeds	–	3238	2318
Juveniles	357	142	90
Non-reproducing adults	17	16	70
Reproducing adults	43	46	35
Fecundity (seeds/repr. plant)	75.3	50.4	16.4
Tel Arad (T-A)			
Seeds	–	592	199
Juveniles	25	23	22
Non-reproducing adults	66	33	67
Reproducing adults	19	38	19
Fecundity (seeds/repr. plant)	31.2	5.25	8.4

– = not estimated

Effect of rhizome initial size on growth and flowering

The results of this experiment (Table 5) clearly show that sexual reproduction (i.e., production of a flower) in *I. atrofusca* depends on the rhizome weight and two size-related parameters, namely length of the leaves and base diameter. The minimal rhizome weight for flowering appears to be around 2.7 g-3.0 g, but probability of flowering for such plants is less than 10% (Fig. 5). The optimal rhizome weight with reasonably high probability of flowering (around 50%) is above 4 g (Fig. 5).

Creation of *quasi in situ* living collections

Two years after planting, survival rates in two living collections were equally high, approximating 100%. Percent of flowering plants was substantially higher in Tel Beer

Table 5. Results of multiple logistic regression testing effect of five predictor variables on probability of flowering.

Parameter	Wald Statistics	p
Intercept	0.24	0.6210
Rhizome weight	30.76	< 0.0001
Leaf length	13.46	0.0002
Leaf width	0.15	0.7008
Base diameter	4.20	0.0403
Number of leaf-fans	1.26	0.2618

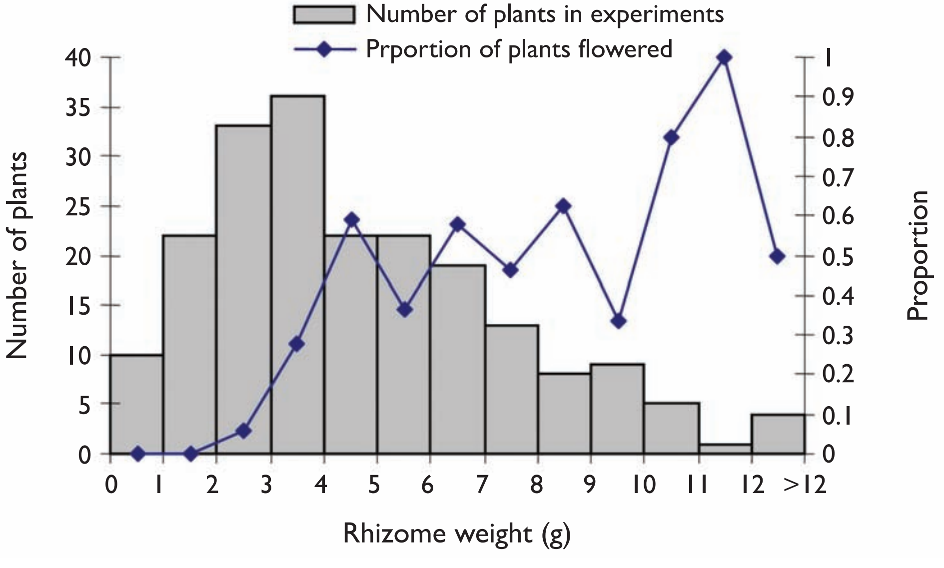

Figure 5. Proportion of plants flowering and total number of plants of different rhizome weight classes in the experiment described in the text.

Sheva National Park than Tel Arad National Park, while a difference in percentage of plants that produced mature fruits was less pronounced (Fig. 6). Plants of native geographic origin had no advantage at either location.

A high percentage of flowering plants at one location (Tel Beer Sheva National Park) indicates high potential seed productivity in the living collection. The low percentage of plants that set fruits appears to result from low numbers of pollinators in this area. Therefore the genetic refuges can be a source of seeds for relocation once artificial pollination is provided.

Large scale relocation experiment

High survival rates were observed in the first year after introduction at all locations, and the highest number of reproducing plants was observed at Ofakim and Lahav North (Fig. 7). At Har Amasa, plant above-ground biomass was browsed by grazing livestock, thus, assessment of reproduction was not possible. Two years after the introduction a difference in plant survival rates among the locations started to become obvious (Fig. 7). Grazing at Har Amasa again prevented assessment of plant reproduction.

The most unexpected and counterintuitive result was zero reproduction at two experimental sites established in close proximity to the natural populations, G-G and T-A. In both cases experimental locations were established on an adjacent hill slope. This indicates the importance of microscale conditions for relocation success. At the

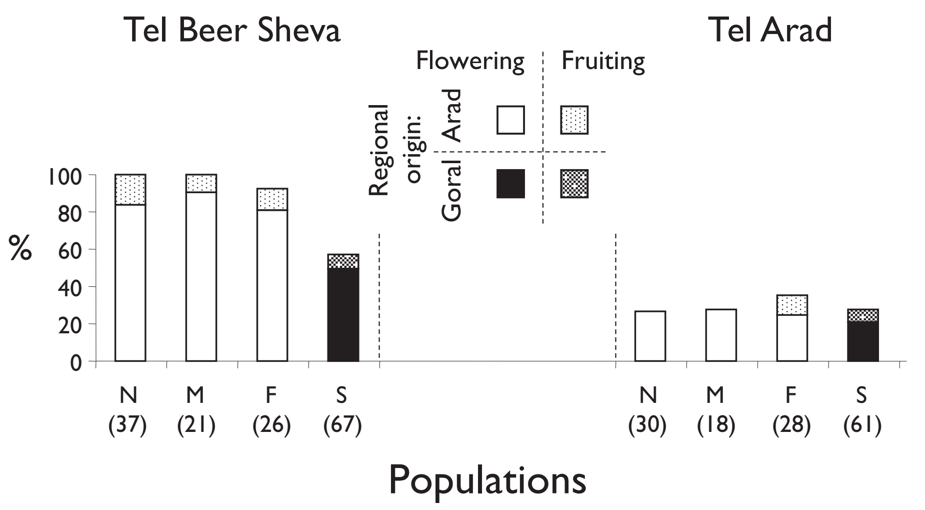

Figure 6. Population name, number of genetically distinct individuals (in parentheses), and percentage of flowered and fruited plants two years after creation of two *quasi in situ* collections in Tel Beer Sheva and Tel Arad National Parks, respectively.

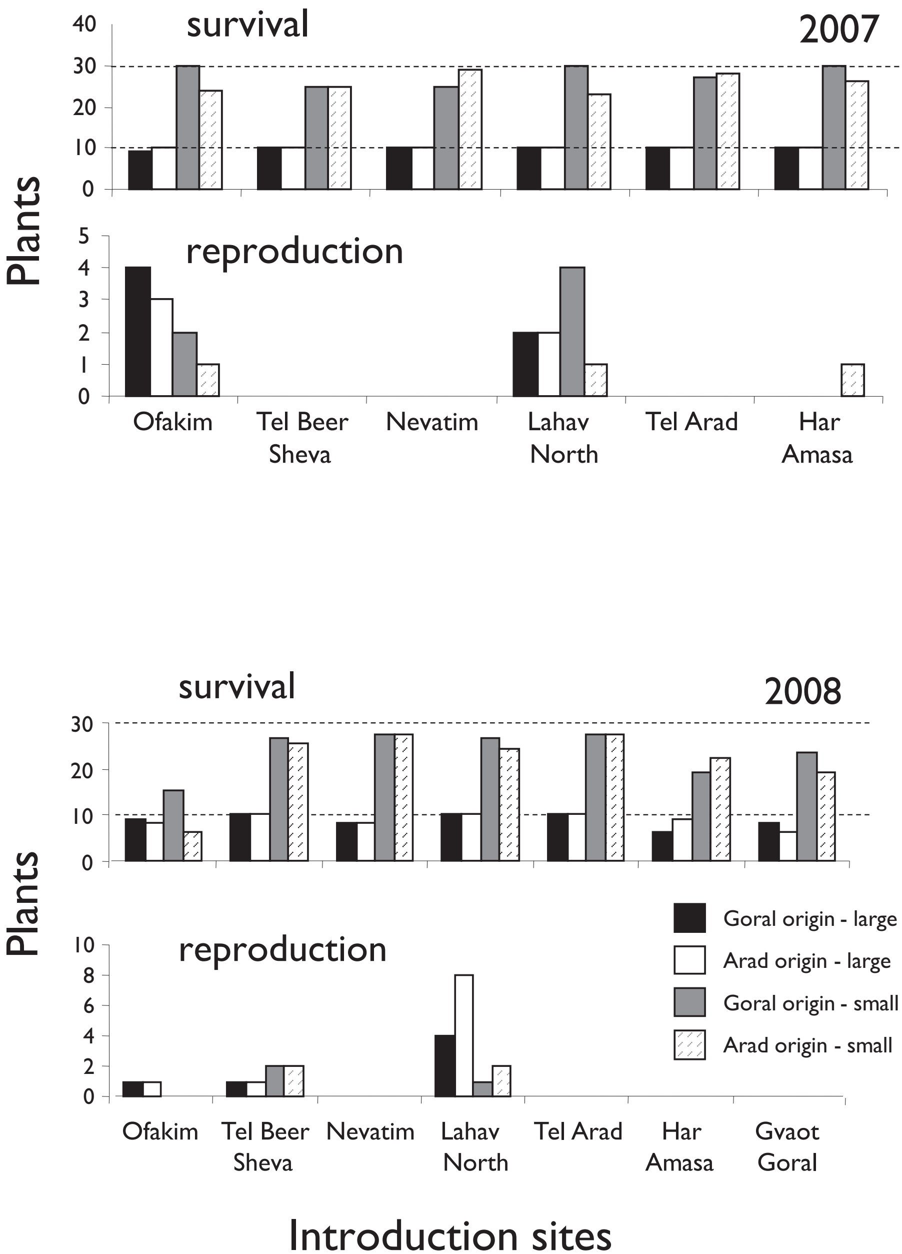

Figure 7. Survival and reproduction of *I. atrofusca* one year after experimental introduction. Ten large (> 20 g) and 30 small (5–10 g) rhizomes of Goral Hills and Arad Valley origin were introduced at each site.

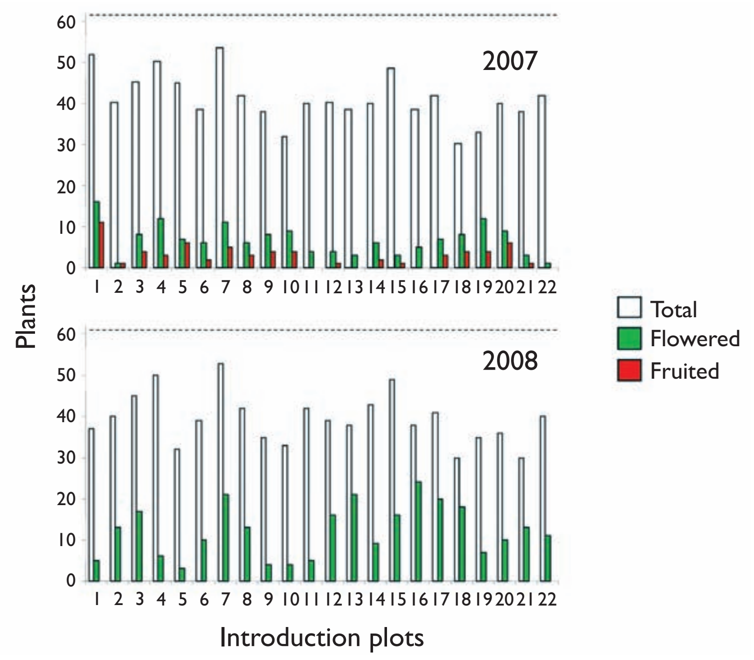

Figure 8. Survival and reproduction of *I. atrofusca* one year after experimental introduction at Lahav North Reserve. Sixty-two rhizomes of Goral Hills origin with equal representation of different size classes were introduced at each introduction plot.

Lahav North Reserve both survival and reproduction of plants were consistently high during two years of observations. This strongly supports our decision made in 2006 to start experimental microscale relocation at the Lahav North Reserve. At the Ofakim site reproduction was high in the first year but dropped dramatically in the second year after planting.

Small scale relocation experiment

The number of plants observed at the 22 microsites in the Lahav North Reserve one year after introduction ranged from 25 to 52 plants (out of 62 introduced) with no significant difference between microsites (G-test, $G_{.05,21} = 9.2$, $p > 0.05$; Fig. 8). The microsites did not differ either in the number of plants that set fruits (G-test, $G_{.05,21} = 32.4$, $p > 0.05$), but differed in numbers of flowering plants (G-test, $G_{.05,21} = 36.8$, $p < 0.05$).

Two years after the introduction, the range of surviving plants per microsite was between 33 and 53, generally higher than the previous year records. This indicates that some plants were not counted in the first year census, perhaps due to rhizomes dormancy. As in the first year, no microsite difference was observed for plant survival in the second year (G-test, $G_{.05,21} = 20.0$, $p > 0.05$), but numbers of reproducing plants were significantly different among microsites (G-test, $G_{.05,21} = 74.2$, $p < 0.001$; Fig. 8).

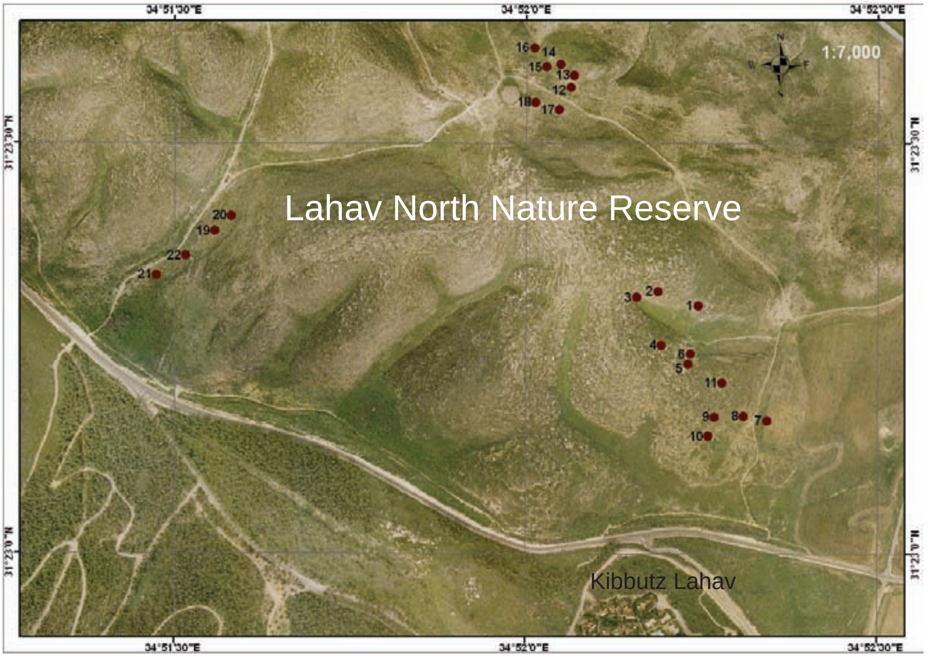

Figure 9. Map of the Lahav North Reserve with 22 microsites at which identical sets of *I. atrofusca* rhizomes were planted.

Contrary to the first year, no flower set fruit at any microsite in the second year. All the flowers were consumed by grasshoppers and caterpillars, indicating the important role of biotic interactions at the Lahav North site.

Discussion

Distribution in the Negev and population demography

The observed differences in stage structure (i.e. the frequency of life-cycle stages) between the two populations correspond to two types of demographic behavior, the "invasive" or "dynamic" (Gvaot Goral) and "normal" or "stable" (Tel Arad) (Rabotnov 1969, 1985, Oostermeijer et al. 1994). The former is characterized by a higher proportion of immature plants relative to the adults, while in the latter the adults predominate and the young individuals are low in number. These two population types are usually associated with different succession stages of the local vegetation community, but in the two *I. atrofusca* populations studied no difference was apparent with respect to the succession stage. One major difference between the two population locations is in aridity, and the observed difference in a proportion of immature plants appears to be due to higher survival of seedlings (although survival of juveniles does not differ) at less xeric Gvaot Goral site. Nonetheless, it is too early to draw conclusions about the long-term dynamics of these two populations. The latter requires a multi-year census coupled with records of annual rainfall and assessment of grazing pressure.

The two groups are separated from each other by a distance of ca 20 km with hardly any gene flow between them. Different environmental conditions (soil, rainfall) and anthropogenic impact (intensive grazing vs agriculture) may have caused differential selective responses in the two regions. Therefore an *I. atrofusca* conservation strategy must be based on the assumption that ecologically important (i.e. adaptive and caused by biotic/abiotic environmental variation) exists within *I. atrofusca* in the Negev and regional criterion (Goral Hills vs Arad Valley range subdivision) is a first approximation of this variation. This assumption has several implications for this species *ex* and *in situ* conservation.

Ex situ **implications**

If plants in two regions are adapted to different environmental conditions, sampling and maintenance of living collections must be done for each region separately. Mixing or physical proximity of plants having different regional origin must be prevented. If, due to logistical limitations, plants are maintained in the same location, measures must be taken to prevent spontaneous hybridization (e.g. removal of immature fruits). On the other hand, interbreeding of plants originating from different populations within the same region, is desired to decrease risk of inbreeding depression and self-incompatibility. The latter negative effects were detected in fragmented populations of *I. bismarckiana*, a close relative to *I. atrofusca* (Segal et al. 2007).

In our study, plants from five populations of *I. atrofusca* in the Negev were planted at two National Parks, creating two duplicates of the same living collection. After careful study of region-specific environmental conditions, anthropogenic impacts and population demography we concluded that we should divide our collection based on a regional criterion. In spite of the initial proximal planting of plants from two regions, no spontaneous hybridization occurred during two years of collection maintenance because of the precautions described above.

After removal and re-planting of populations representing the Goral Hills area, into their region-specific location in Tel Beer Sheva National Park, and populations from the Arad Valley area into their region-specific location at Tel Arad National Park, the next step in applying *quasi in situ* conservation, using plants in the living collections for seed propagation. In a case of low fruit set due to limited availability of natural pollen vectors (*Eucera* bees; Sapir et al. 2005) randomly applied artificial pollination should be performed. The seeds obtained can be treated to reduce strong innate dormancy, and germinated in mass. Young plants with rhizomes acceding 4 g can be used for *in situ* actions, which should be performed with plants of proper regional origin.

In situ implications

Rapid destruction of *I. atrofusca* natural environment in the Northern Negev due to heavy anthropogenic impact on the one hand, and lack of nature reserves that contain populations of *I. atrofusca* in the Negev, on the other hand, leaves very limited options for conservation of this species. Declaration of new protected areas in the northern Negev is very problematic because of economic, demographic and political issues. There is virtually no vital alternative to relocation, i.e. introduction of the species into presumably suitable protected areas with no previous records of the species. At the same time, the choice of such areas for *I. atrofusca* in the Negev is limited.

It is too early to draw conclusions from our relocation experiments, started in 2006, about factors limiting species distribution. At least several more years are needed for reliable conclusions, because among-year fluctuations, as well as long-term effects should be considered. However, some general considerations about a choice of relocation material can be done even at this stage. Using regional subdivision as a guideline for successful relocation, creation of a new population within Goral Hills or Arad Valley region should be done using material from the same region. If, however, a new population location can not be ascribed to one of these regions, possible options include material of single regional origin (either Goral or Arad) or a mix of two. Although lack of local adaptation is not an issue here, hybridization of two ecotypes may result in a disruption of coadapted gene complexes, high genetic load and low average fitness of plants in the new population. As a result relocation success may be low. Without relocation experiments, it is impossible to decide which of two plant origins is more suitable.

Conclusions

We conclude that the proposed approach assessing ecological importance, and using this information for both, *ex* and *in situ* conservation is suitable for endangered species that are distributed over areas with complex and variable ecological conditions. We hope that detailed guidelines developed from the above approach for: (1) representative sampling of populations; (2) collection maintenance; and (3) utilization for *in situ* actions will be used as a tool for efficiently solving specific conservation problems.

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References

Aguilar R, Quesada M, Ashworth L, Herrerias-Diego Y, Lobo J (2008) Genetic consequences of habitat fragmentation in plant populations: susceptible signals in plant traits and methodological approaches. Molecular Ecology 17: 5177–5188.

Allen WH (1994) Reintroduction of endangered plants. BioScience 44: 65–68.

Arafeh RMH, Sapir Y, Shmida A, Iraki N, Fragman O, Comes HP (2002) Patterns of genetic and phenotypic variation in *Iris haynei* and *I. atrofusca* (*Iris* sect. *Oncocyclus* = the royal irises) along an ecogeographical gradient in Israel and the West Bank. Molecular Ecology 11: 39–53.

Atlas of Israel (1985) Atlas of Israel, Survey of Israel, Tel Aviv (3rd edition).

Avishai M, Zohary D (1980) Genetic affinities among the *Oncocyclus* irises. Botanical Gazette 141: 107–115.

Barrett SC, Kohn JR (1991) Genetic and evolutionary consequences of small population size in plants: implications for conservation. Pp. 3–30 In: Falk DA, Holsinger KE (Eds) Genetics and Conservation of Rare Plants. Oxford University Press, New York.

Blecher M (2007) *Iris atrofusca* of the Nothern Negev: survey, preliminary results. Israel Nature and Parks Authority.

Bottin L, Cadre S Le, Quilichini A, Bardin P, Moret J, Machon N (2007) Re-establishment trials in endangered plants: A review and the example of *Arenaria grandiflora*, a species on the brink of extinction in the Parisian region (France). Ecoscience 14: 410–419.

Brown ADH, Briggs JD (1991) Sampling strategies for genetic variation in ex situ collections of endangered plant species. Pp. 99–122 In: Falk DA, Holsinger KE (Eds) Genetics and Conservation of Rare Plants. Oxford University Press, New York.

Brown ADH, Marshall DR (1995) A basic sampling strategy: theory and practice. Pp. 75–111 In: Guarino L, Ramantha Rao VR (Eds) Collecting plant genetic diversity: technical guidelines. CAB International Wallington, UK.

Cranston DM, Valentine DH (1983) Transplant experiments on rare plants species from Upper Teesdale. Biological Conservation 26: 175–191.

Danin A (1988) Flora and vegetation of Israel. Pp. 129–157 *in* Y. Yom-Tov and E. Tchernov, eds. The Zoogeography of Israel. Junk, Dordrecht.

Danin A (2004) Distribution atlas of plants in the flora Palaestina area. Israel Academy for Science and Humanities, Jerusalem.

Ellstrand NC, Elam DR (1993) Population genetic consequences of small population size: implications for plant conservation. Annual Review in Ecology and Systematics 24:217–242.

Falk, D. A. 1987. Inegrated conservation strategies for endangered plants. Natural Areas Journal 7: 118–123.

Feinbrun-Dothan N (1986) Flora Palaestina. Israel Academy of Sciences and Humanities, Jerusalem.

Given DR (1987) What the conservationist requires of ex situ collections In: Bramwell D, Hamann O, Heywood VH, Synge H (Eds) Botanic gardens and world conservation strategy. Academic Press, London.

Hedrick PW, Kalinowski ST (2000) Inbreeding depression in conservation biology. Annual Review in Ecology and Systematics 31: 139–162.

Heywood VH, Iriondo JM (2003) Plant conservation: old problems, new perspectives. Biological Conservation 113: 321–335.

Holland PG (1980) Transplant experiments with trout lily at Mont St. Hilaire, Quebec Journal of Biogeography 7: 261–267.

Hufford KM, Mazer SJ (2003) Plant ecotypes: genetic differentiation in the age of ecological restoration. Trends in Ecology and Evolution 18: 147–155.

Husband BC, Campbell LG (2004) Population responses to novel environments: implications for ex situ plant conservation In: Guerrant EOJ, Havens K, Maunder M (Eds) Ex situ plant conservation: Supporting species survival in the wild. Island Press, Washington.

Jaffe S (1988) Climate of Israel. Pp. 129–157 In: Yom-Tov Y, Tchernov E (Eds) The Zoogeography of Israel. Junk, Dordrecht.

Joshi J, Schmid B, Caldeira MC, Dimitrakopoulos PG, Good J, Harris R, Hector A (2001) Local adaptation enhances performance of common plant species. Ecology Letters 4: 536–544.

Keller LF, Waller DM (2002) Inbreeding effects in wild populations. Trends in Ecology and Evolution 17: 230–241.

Kushnir T (1949) Leaf spot diseases of *Iris* in Palestine. Palestine Journal of Botany, Jerusalem series 4: 230-233.

Lande R, Barrowclough GF (1987) Effective population size, genetic variation, and their use in population management. Pp. 87–124 In: Soule ME (Ed) Viable populations for management. Cambridge University Press, Cambridge.

Linhart YB, Grant MC (1996) Evolutionary significance of local genetic differentiation in plants. Annual Review of Ecology and Systematics 27: 237–277.

Maunder M, Havens K, Guerrant EOJ, Falk DA (2004a). Ex situ methods: a vital but underused set of conservation resources. Pp. 3–20 In: Guerrant EOJ, Havens K. Maunder M (Eds) Ex situ plant conservation: Supporting species survival in the wild. Island Press, Washington.

Maunder M, Hughes C, Hawkins JA, Culham A (2004b) Hybridization in ex situ plant collections: conservation concerns, liabilities, and opportunities. Pp. 325–364 In: Guerrant EOJ, Havens K, Maunder M (Eds) Ex situ plant conservation: Supporting species survival in the wild. Island Press Washington.

Menges ES (2008) Restoration demography and genetics of plants: when is a translocation successful? Australian Journal of Botany 56: 187–196.

Millar CI, Libby WJ (1991) Strategies for conserving clinal, ecotypic, and disjunct population diversity in widespread species. Pp. 149–170 In: Falk DA, Holsinger KE (Eds) Genetics and conservation of rare plants. Oxford University Press, New York.

Morton JK (1982) Preservation of endangered species by transplantation. The Canadian Botanical Association Bulletin 15:32.

Newman D, Pilson D (1997) Increased probability of extinction due to decreased genetic effective population size: Experimental populations of *Clarkia pulchella*. Evolution 51: 354–362.

Newman D, Tallmon DA (2001) Experimental evidence for beneficial fitness effects of gene flow in recently isolated populations. Conservation Biology 15: 1054–1063.

Oostermeijer JGB, Vantveer R, Dennijs JCM (1994) Population structure of the rare, long-lived perennial *Gentiana pneumonanthe* in relation to vegetation and management in the Netherlands. Journal of Applied Ecology 31: 428–438.

Rabotnov TA (1969) On coenopopulations of perennial herbaceous plants in natural coenoses. Vegetatio 19: 87–95.

Rabotnov TA (1985) Dynamics of plant coenotic populations. Pp. 121–142 In: White J (Ed) The population structure of vegetation. Handbook of vegetation science, Junk, Dordrecht.

Sapir Y, Shmida A, Fragman O (2003) Constructing red numbers for endangered plant species - Israeli flora as a test case. Journal for Nature Conservation 11: 91–107.

Sapir Y, Shmida A, Fragman O, Comes HP (2002) Morphological variation of the *Oncocyclus* irises (*Iris* : Iridaceae) in the southern Levant. Botanical Journal of the Linnean Society 139: 369–382.

Sapir Y, Shmida A, Ne'eman G (2005) Pollination of *Oncocyclus* irises (*Iris* : Iridaceae) by night-sheltering male bees. Plant Biology 7: 417–424.

Schaal B, Leverich WJ (2004) Population genetic issues in ex situ plant conservation. Pp. 267–285 In: Guerrant EOJ, Havens K, Maunder M (Eds) Ex situ plant conservation: Supporting species survival in the wild. Island Press, Washington.

Segal B, Sapir Y, Carmel Y (2007) Fragmentation and pollination crisis in the self-incompatible *Iris bismarckiana* (Iridaceae), with implications for conservation. Israel Journal of Ecology and Evolution 52: 111–122.

Shimshi D (1979/80) Two ecotypes of *Iris atrofusca* Bak. and their relations to man-modified habitats. Israel Journal of Botany 28: 80–86.

Shmida A, Pollak G (2007) Red Data Book: Endangered Plants of Israel. Israel Nature and Parks Authority.

Tallmon DA, Luikart G, Waples RS (2004) The alluring simplicity and complex reality of genetic rescue. Trends in Ecology & Evolution 19: 489–496.

Uma Shaanker R, Ganeshaiah KN (1997) Mapping genetic diversity of *Phyllanthus emblica*: Forest gene banks as a new approach for in situ conservation of genetic resources. Current Science 73: 163–168.

Uma Shaanker R, Ganeshaiah KN, Nageswara Rao M, Ravikanth G. (2001) A new approach to conservation of genetic resources of forest trees: promise and processes. Pp. 263–271 In: Uma Shaanker R, Ganeshaiah KN, Bawa KS (Eds) Forest genetic resources: Status, threats and conservation strategies. Oxford and IBH Publishing Co. Pvt. Ltd

Uma Shaanker R, Ganeshaiah KN, Nageswara Rao M, Ravikanth G. (2002) Forest gene banks – a new integrated approach for the conservation of forest tree genetic resources. Pp. 229–235 In: Engels JMM, Brown AHD, Jackson MT (Eds) Managing plant genetic resources. CABI Publishing, Nosworthy. UK.

Volis S, Mendlinger S, Ward D (2002) Differentiation in populations of *Hordeum spontaneum* along a gradient of environmental productivity and predictability: life history and local adaptation. Biological Journal of the Linnean Society 77: 479–490.

von Bothmer R, Selberg O (1995) Strategies for the collecting of wild species. Pp. 93–111 In: Guarino L, Ramantha Rao VR (Eds) Collecting plant genetic diversity: technical guidelines. CAB International Wallington, UK.

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RESEARCH ARTICLE

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Key Biodiversity Areas: Rapid assessment of fish fauna in southern Iraq

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Abstract
Surveys of fish in the southern marshes of Iraq are an integral component of the Key Biodiversity Areas (KBA) Project that was initiated in 2005 by Nature Iraq. This included sampling in the January to February and June periods of 2005, 2006 and 2007. Fish species occurrence, relative abundance, and weight and length were recorded. Species of importance for local consumption were noted. An initial project report included details and photographs of the species observed in 2005. Records based on interviews with local residents are noted. Sixteen "Species of Special Concern" are proposed, considering both economic and ecological factors that may be relevant to a future national fish management strategy in Iraq.

Keywords
Key biodiversity areas, inland water fish, Iraq

Introduction

The Mesopotamian marshlands are a part of the Tigris-Euphrates Basin, considered by many as the "cradle of civilization". The Basin, the largest river system in southwest Asia, has been the focus of the Key Biodiversity Areas Project since 2005, as summarized by Rubec and Bachmann (2008).

Some 106 species of fish (including freshwater and marine entrant species) have now been recorded in the non-marine waters of Iraq (Coad et al. in preparation), significantly expanding earlier species lists published by Al-Daham (1988) and Coad (1991) for Iraqi freshwaters. Additional marine fish species also occur in the marine territorial waters of Iraq but are not yet the focus of new studies in Iraq. The native fish of the southern marshes have historically been dominated by cyprinid species (*Barbus* spp.). In 1990, prior to major drainage of the southern marshes of Iraq, the United Nations Food and Agriculture Organization (FAO) estimated that the inland catch of fish in Iraq was 23,600 tonnes/year with about 60% of this catch coming from the southern marshes of the country. Since that time, inland catches were seriously reduced, this being directly related to habitat destruction and water quality decline. In addition, coastal fisheries in the Gulf, historically depended on portions of these marshes as spawning grounds and nursery areas for penaeid shrimp and many marine fish species, were seriously disrupted (Richardson and Hussain 2006).

These marshes, a natural refuge for aquatic organisms especially fish and birds, were characterized by their high primary productivity of aquatic plants including phytoplankton (Al-Hilli 1977, Al-Zubaidy 1982). The desiccation of the vast Mesopotamian marshlands, one of the world's most significant wetlands and a centre of global importance for biodiversity, took place primarily in the 1990s (Partow 2001). This was a specific policy of the previous Iraqi regime, aimed at thwarting an uprising in the south of the country that occurred following the 1991 Gulf War. In a few short years, the marshlands were nearly destroyed and effects on the marshes and the Gulf were severe, with significant reductions in population size of all fish and shellfish species important to fisheries. After the end of the previous Iraqi regime in 2003, water was restored to much of the marshland area. Biodiversity surveys, suspended in the area for several decades, were resumed. This has included the KBA Project as a key component.

Methodology

The KBA surveys used a rapid assessment approach during the winter and summer periods of 2005, 2006, and 2007. Rapid assessment focused on limited sampling, speed, and efficiency in terms of costs and logistics – all being practical requirements for field studies in Iraq due to the security and evolving political situation in Iraq since 2003. Fish surveys, as an integrated component of the KBA project along with other disciplines, have generated samples collected from fishermen who used various methods, including:

- Fixed nets: 1.5 m high by 200–1000 m long with mesh size ranging from 2 cm to 8 cm, which are set and retrieved in a two-person process. These nets are locally-made.
- Seine nets: 10 m high by 500 m long, which require 12 people to set and gather.
- Electro-shocking: 220–300 V appliances are used to create a localized electrical field using a 2 m electrified net with a 0.5 cm mesh size usually attached to a pole. The appliances used are either truck batteries or small gas generators.
- Poisons of various kinds and gill netting.

Fish collected from the local markets and interviews held with fishermen and other local residents were additional sources of information. The field team purchased the fish samples directly from fishermen; after the field trips these fish were transported to the lab in an ice-chest. Fish were identified to family, genus and species, and counts, weights and lengths were recorded. Species were identified using Khalaf (1961), Mahdi (1962) and Al-Daham (1982), and then verified against keys prepared for the forthcoming book by Coad et al. (in preparation) as well as the Canadian Museum of Nature's Middle East database maintained by Coad (www.briancoad.com).

Fish fauna observations

Table 1 summarizes observations of fish species in 12 marsh sites surveyed in 2005, 2006 and 2007. The location of the Central Marsh, Hammar Marsh and Hawizeh Marsh relative to the full scope of KBA studies in the southern marshes of Iraq are shown in Fig. 1. Table 2 summarizes the number of fish species observed at all field sites in the summer and winter of the 2005–06, in the summer of 2006 and in the winter and summer of 2006–07. Five additional sites in southwestern Hammar Marsh were visited in 2005 but these sites were dry with no fish.

Twelve different fish species were recorded in the 2005 summer surveys. With the completion of the winter 2005–06 survey, the total number of fish species recorded

Table 1. Location of fish species observed in the central Hammar and Hawizeh Marshes of Iraq from 2005 to 2007. (Sources: Abd 2005, Abd 2006a, Abd 2006b)

Fish Species and Common Arabic Name†	Sampling Areas ‡ §				
	Central Marsh	Hammar Marsh-Northwest	Hammar Marsh-South	Hammar Marsh-East	Hawizeh Marsh
Acanthobrama marmid (Semnan arez)	CM1–CM2	HA6		HA14–HA16	HZ1, HZ2, HZ3, HZ4, HZ5, HZ6, HZ7
Alburnus mossulensis (Semnan tuyel)	CM1–CM2	HA6		HA14–HA16	HZ1, HZ2, HZ3, HZ4, HZ5, HZ6, HZ7
Aspius vorax (Shillik)	CM1			HA14–HA16	HZ1–HZ7
Aphanius dispar (Batrikh)	CM2			HA14–HA16	
Barbus grypus (Shabout)	CM1				HZ1
Barbus luteus (Himri)	CM1–CM2, CM3*	HA3, HA4*		HA14–HA16	HZ1–HZ7

Fish Species and Common Arabic Name†	**Sampling Areas ‡ §**				
	Central Marsh	**Hammar Marsh-Northwest**	**Hammar Marsh-South**	**Hammar Marsh-East**	**Hawizeh Marsh**
Barbus sharpeyi (Bunni)				HA14–HA16	HZ1–HZ5
Barbus xanthopterus (Gattan)	CM1				HZ1
Carassius auratus (Buj-Buj)	CM1, CM3*, CM4*	HA1–HA3, HA4*	HA9–HA12	HA14–HA16	HZ1
Cobitis sp. (Loach)					HZ1
Ctenopharyngodon idella (Carp Eshaby)	CM1	HA4*			
Cyprinus carpio (Samti)	CM1–CM2, CM3*	HA2, HA4*		HA14–HA16	HZ1, HZ2*, HZ4, HZ5
Liza abu (Khishni)	CM1–CM2, CM3*, CM4*	HA1–HA3	HA9–HA12	HA14–HA16	HZ1– HZ7
Mastacembelus mastacembelus (Abu Salambah)	CM1, CM3*	HA1		HA14–HA16	HZ1, HZ2, HZ3*, HZ4, HZ5
Mystus pelusius (Abu Al-Zummiar)	CM1, CM2, CM3*			HA14–HA16	HZ1, HZ2, HZ3*
Silurus triostegus (Jirri)	CM1, CM2, CM3*	HA2		HA14–HA16	HZ1, HZ2*, HZ3*, HZ4, HZ5
Total no. of Fish Species Observed	**14**	**9**	**2**	**12**	**15**

† Species here are listed alphabetically versus systematically.

‡ Records that are based on local interviews are marked with a single asterisk (*).

§ Sites sampled are listed below:

Central Marsh (CM): CM1 (Abu Zirig Marsh); CM2 (Chubayish Marsh); CM3 (Al Auda Marsh); and CM4 (Al Rayan Marsh) (Note: CM4 was dry from the summer of 2006 through the 2007 surveys).

Hammar Marsh (HA) – Northwest: HA1 (Northern 'Teena); HA2 (Southern 'Teena); HA3 (Buhaira Al Hilwa); HA4 (Umm Al Tiyaar near Al Buhaira); HA6 (Umm Nakhla); HA7 (Khwaysa Area in Al Kermaashiya Marsh); and HA8 (Kermaashiya Marsh).

Hammar Marsh (HA) – South: HA9 (Southern Hammar Marshes); HA10 (Western Sinaaf Marsh); and HA11 (Shuwaya'riya Area) ; HA12 (Eastern Sinaaf Marsh).

Hammar Marsh (HA) – East: HA14 (Mas'hab Area); HA15 (Sallal); and HA16 (Naggaara).

Hawizeh Marsh (HZ): HZ1 (Umm Ni'aaj Marsh); HZ2 (Udhaim Marsh); HZ3 (Sewaalif Marsh); and HZ4, HZ5, HZ6 and HZ7 (E'jayrda Marshes).

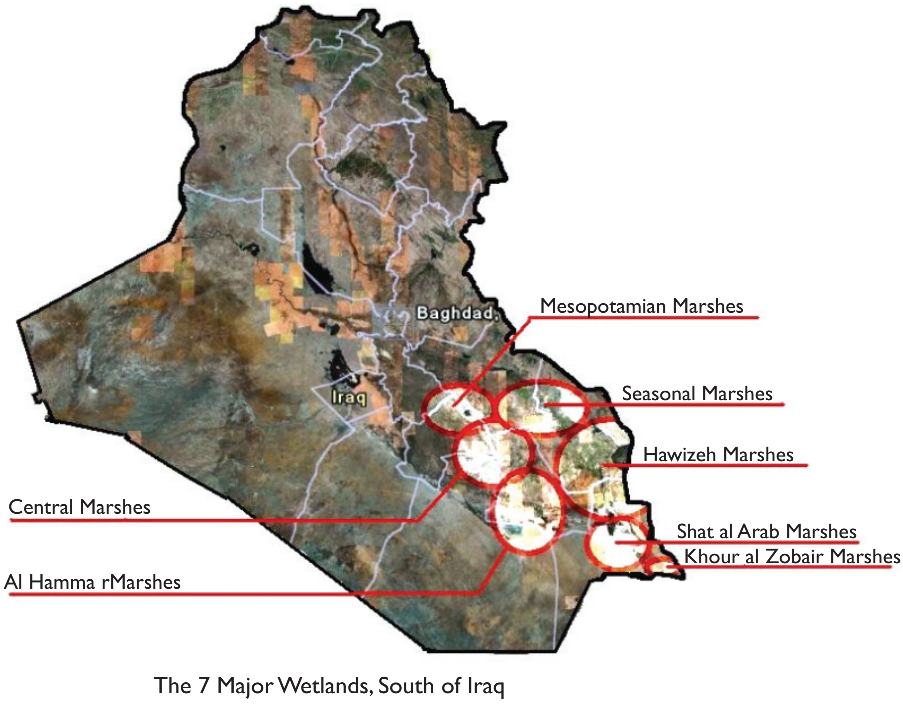

Figure 1. Study areas for the KBA Project in Iraq.

and/or observed in the 2005–06 fiscal year rose to 44 (17 freshwater and 27 marine species). In the summer 2006 surveys, 41 species (16 freshwater and 25 marine species) were recorded with a different mix of the marine species that had been observed in 2005–06. Surveys in 2007 added five more freshwater species (*Cobitis* sp., *Alburnus caeruleus, Barbus esocinus, Cyprinion kais* and *Aphanius mento)*, thus totaling 52 species recorded in the surveys in 2006–07.

Freshwater fishes of Iraq – a new field guide

In 2009, it is hoped that a new book, *The Freshwater Fishes of Iraq*, will be published (Coad et al. in preparation). It will include line drawings, species status, biological descriptions and selected photographs of 43 freshwater, 10 exotic, and 53 species of marine origins, in total 106 species of fish that are found in the inland waters of Iraq.

The book project has received support from Nature Iraq; the Italian Ministry of Environment, Land and Sea; the Canadian International Development Agency; and the Canadian Museum of Nature. The book will also include information on the economic importance and conservation concerns for each species of fish listed. An interpretation of the data in this forthcoming book for Iraqi fish species is here

Table 2. Number of fish species observed in 2005-2007 surveys (all sites).

Family	Number of Species Observed in Summer 2005 and Winter 2005/06	Number of Species Observed in Summer 2006	Number of Species Observed Winter 2006/07 and Summer 2007
Freshwater Species			
Cyprinidae	11	10	14
Cobitidae (new record in southern Iraq)	--	--	1
Bagridae	1	1	--
Siluridae	1	1	1
Heteropneustidae	1	1	1
Cyprinodontidae	--	--	1
Mugilidae	2	2	2
Mastacembelidae	1	1	1
Marine Species			
Engraulidae	1	1	2
Chirocentridae	1	1	1
Clupeidae	4	3	3
Synodontidae	--	--	--
Exocoetidae	--	--	1
Belonidae	1	1	1
Platycephalidae	--	1	1
Serranidae	1	1	3
Sillaginidae	--	1	1
Carangidae	1	--	2
Lutjanidae	--	1	--
Gerreidae	1	--	--
Haemulidae	--	--	1
Nemipteridae	1	1	--
Lethrinidae	2	--	1
Sparidae	3	2	5
Polynemidae	1	1	1
Sciaenidae	3	3	3
Drepaneidae	--	--	1
Chaetodontidae	--	1	1
Siganidae	2	1	--
Scombridae	1	2	--
Stromateidae	--	1	1
Bothidae	2	2	--
Soleidae	1	--	1
Cynoglossidae	1	1	1
Total Number of Species Observed	**44**	**41**	**52**

offered as a preliminary listing of fish species that may require conservation management in Iraq. Sixteen proposed "Species of Special Concern (SSCs)" (as prepared by Rubec and Coad 2007) are presented in Table 3. The concept of "SSC" is used here in the same context as protocols developed by organizations such the World Conservation Union (IUCN) and BirdLife International for birds, mammals and other fauna. This would include species that are identified as globally endangered, threatened, near threatened or vulnerable. The most recent global listings are noted in IUCN (2009) but these do not recognize species at risk that are identified only at a national scale. Coad et al. (in preparation) provide data on the economic importance of fish species in Iraq, while Rubec and Coad (2007) have developed an interpretation of ecological importance of fish species. Regrettably, no national or current fisheries assessment is available in Iraq which would permit official listing of species at risk in that country. Thus, in this current paper, particular fish species are noted by the authors as possible "SSCs" because they are generally ranked "high" in economic importance and also "high" or "possibly high" due to conservation concerns, are believed or known to be "rare" or "endangered" as a species in Iraq or elsewhere (such as in bordering nations), or are on the IUCN Red List (IUCN 2009). The data presented in Table 3 is meant only as a starting point for ongoing development and review in Iraq. It could provide guidance for further development of fish species and fishery stocks conservation and management measures.

In Coad et al. (in preparation) and as summarized in Table 3, five *Barbus* species are identified as under ecological or economic pressure, particularly in neighbouring countries. It is speculated that this also applies to Iraq. It should be noted that *Aphanius mento* is locally abundant but does not appear to be widely distributed, so it could also be a species at risk nationally in Iraq (it is rarely collected and easily missed as surveys have tended to concentrate on the larger commercial species). The marine species, including the families Carcharhinidae (except *Carcharhinus leucas*), Engraulidae, Clupeidae (except *Tenualosa ilisha* which spawns in freshwater), Ariidae, Mugilidae (except *Liza abu*, a freshwater resident), Hemiramphidae, Belonidae, Platycephalidae, Sillaginidae, Sparidae, Sciaenidae, Gobiidae, Scatophagidae, Stromateidae and Soleidae are all represented by marine populations which are in their "normal" habitat. This is because the economic importance, numbers and conservation needs of these marine species are generally not assessed in Coad et al. (in preparation) which is focused on the species occurring in the freshwater biome of Iraq. However, as many of the marine fish are rare or occasional migrant species to those freshwaters, they are generally not breeding or maintaining large populations in the freshwaters of Iraq. There are also some marine species that have been introduced into saline lakes of Iraq such as *Acanthopagrus latus* (Coad, personal observation).

Discussion of fish fauna in the southern marshes of Iraq

In three years of surveys from 2005 to 2007, the KBA project fish surveys have recorded observations in a range of 41 to 52 fish species (including freshwater and marine entrant species) in the marshes of southern Iraq. The dominant fish in the marshes as recorded by Abd (2005, 2006a, b) for the Nature Iraq Key Biodiversity Areas surveys from 2005–2007 are from the family Cyprinidae. This was also reported

Table 3. Economic importance and potential conservation priority for 16 proposed Iraqi fish "Species of Special Concern" (Sources: Coad et al. in preparation, Rubec and Coad 2007).

Species	Common Names in Arabic and in English [in square brackets] †	Economic Importance	Proposed Priority for Conservation Action
Tenualosa ilisha	Sbour; zoboor; soboor; sobour [hilsa, Indian shad or river shad]	High	High.
Alburnoides bipunctatus	None [spirlin, riffle minnow or riffle bleak]	Moderate	High possibly; "vulnerable" in Europe.
Barbus barbulus	Abu-barattum; abu baratem; abu bratum; nabbash	High	High possibly.
Barbus esocinus	Bizz; farkh; farch; farkh-el-biz; mangar [Tigris salmon, Euphrates salmon, pike barb].	High	High possibly; under severe threat in the Syrian Euphrates; part of a world survey to assess the status of large freshwater fish species by the World Wildlife Fund and the National Geographic Society.
Barbus grypus	Shabout; shabbout; hamrawi [large-scaled barb]	High	High in some regions of Iraq; it is in need of conservation in some parts of its range
Barbus subquincunciatus	Abu khazzama; a'djzan; agzan; adzan. [black spot barb, leopard barbel]	Low	Unknown, possibly High; it is now very rare in Iran and "critically endangered". Syrian populations in the Euphrates River and parts of its tributaries are also in a perilous state.
Barbus xanthopterus	Gattan; ghattan; kattan; khattan; nobbash; thekar	High	High; this species is now relatively rare.
Caecocypris basimi	None	None	High; listed as Vulnerable (D2) in the *2004 IUCN Red List of Threatened Species*.
Cyprinion kais	Bunni saghir; bnaini; kais	None	Moderate; this species appears to be rare.
Typhlogarra widdowsoni	Samak aa'ama [Iraq blind barb]	None	High; listed as Vulnerable (D2) on the *2004 IUCN Red List of Threatened Species*
Cobitis taenia	Lakh mukhattat [spined or spiny loach, stone loach, weatherfish, spotted weatherfish, Siberian loach]	Low-moderate	Unknown, possibly high; this species is classified as rare in Europe.
Glyptothorax kurdistanicus	None	None	Moderate-high possibly; poorly known in Iraq and may be rare enough to warrant conservation efforts
Glyptothorax steindachneri	None	None	High possibly; this species is poorly known in Iraq and may be rare enough to warrant conservation efforts should it prove to be a valid taxon.

Species	Common Names in Arabic and in English [in square brackets] †	Economic Importance	Proposed Priority for Conservation Action
Liza abu	Khishni; hishni; hosoon or hashsoun; maid; abu-khraiza; abu sukkanejn [abu mullet, freshwater mullet]	High	Moderate; a ban on fishing from mid-January to mid-May has been recommended.
Liza klunzingeri	Maid; biah; biah zahbee; beyah zhabee [Klunzinger's mullet (keeled mullet and back keeled mullet]	Moderate	Moderate; this species needs to be carefully monitored as it is part of a fishery.
Acanthopagrus latus	Shanak; shagoom; shaam; sha'm; shaem; sheim; sha-om [yellow-finned porgy or seabream, yellow-finned black porgy, Japanese silver bream]	High	Moderate; the status of natural freshwater populations is unclear as they appear quite rare.

† Various versions of Arabic and English common names exist for each species, even within Iraq. This listing does not imply that any of these names are more accurate than those in the next.

by Partow (2001). These remain the most important species in terms of commercial fishery production for the marshes. In terms of dominance in numbers in 2005 to 2007, the leading three species are *Carassius auratus* (locally known as buj-buj), *Liza abu* (khishni) and *Barbus luteus* (himri). The fish that ranks first in catch weights is *Silurus triostegus* (jirri) but this is a species not eaten by local residents for cultural reasons (absence of scales).

These results are comparable to those reported in Richardson and Hussein (2006) – their highest recorded number of species was 23 species in Hammar Marsh, and the lowest was 15 species in Hawizeh Marsh in their 2005 surveys. Those authors also reported greatly reduced catches of the popular, endemic species *Barbus sharpeyi* (bunni), and significant inclusion of marketable but introduced species such as *Carassius auratus* as well as unpopular species such as *Silurus triostegus*. Twenty-two species of fish have been separately reported in the southern reaches of the Tigris River near the city of Qurna (Mohammed 2007) – most of these species were also observed in these KBA surveys. Hussain et al. (2008) report a total of 25 fish species (18 freshwater and seven marine species) in studies of fish composition and ecological indices at three re-flooded marshes in southern Iraq (Suq Al-Shuyukh, Hawizeh and east Hammar marshes) noting the dominant species were *Liza abu* and *Carassius auratus*.

Barbus xanthopterus (gattan) appears to have decreased in abundance in the last several decades which is attributed to drainage of marshes and damage to nursery areas. *Barbus grypus* (shabout) was absent in the 2006 summer KBA survey of all the southern marsh areas. However, Abd (2006b) noted that *B. grypus* has been observed elsewhere in Iraq, notably in the Umm Ar Risaas area near the city of Abadan along the border with Iran.

Of the 16 proposed SSCs in Table 3, *Barbus grypus*, *B. esocinus, B. xanthopterus*, and *Liza abu* are also included. *Barbus sharpeyi*, a fish species further noted in the KBA marsh surveys, may also be of some concern as it is part of the overall *Barbus* family of fish that are all generally under pressure in neighboring countries.

Several areas, where future study and fisheries program development are needed, include:

1. As this aspect of the KBA work was necessarily tied to the field schedule for birds, sampling in other periods of the year with more time for field work is advisable.
2. An assessment of fish food safety needs to be done, as water quality remains poor in many of the areas surveyed.
3. Fish sampling in other regions of Iraq, where field surveys have not yet been possible, is urgently needed.
4. Species that are now observed to be low in abundance will require particular conservation management attention, reduction in fishing, and supplementary production through fish hatcheries and fish farming.
5. National criteria and a listing of fish "Species of Special Concern" should be officially developed for Iraq to assist in targeting conservation and management measures and regulations, both for fisheries stocks and for species at risk.
6. Electro-shocking of fish is practiced in many areas in southern and northern Iraq. Poison and explosives have also been used in certain areas. Particular attention to the introduction of sustainable fishing methods, proper nets and training for local communities and fishermen is urgently needed. This will assist in improving the economic situation for local people and protecting the resource for future generations.

Conclusions

The Key Biodiversity Areas project, based on a rapid assessment approach by Nature Iraq from 2005 to 2007, has identified significant information on the status and distribution of ecologically and economically critical fish species for Iraqis. In three years of surveys, a range of 41 to 52 species (including freshwater and marine entrant species) were recorded in marshes in southern Iraq. Several recommendations are presented for further scientific and management studies. Sixteen fish species are proposed as possible "Species of Special Concern" in consideration of the design of a fisheries management strategy for Iraq based on ecological and economic factors.

Acknowledgements

The surveys supporting the Key Biodiversity Areas Project have involved many individuals over the 2005 to 2007 period and these surveys are continuing. Fish observations in this period have been led at different times by Ibrahem Abd of Nature Iraq and Haider Ibrahem of the Iraqi Ministry of Environment. This paper draws on unpublished field reports and presentations developed by Ibrahem Abd (Abd 2005, Abd 2006a, Abd 2006b). The authors wish to thank Anna Bachmann, who has been the project manager and report editor. Thanks also go to Azzam Alwash, the Director of Nature Iraq. The KBA project is led by Nature Iraq with support by the Canadian International Development Agency from 2004–2006 and by the Italian Ministry of Environment, Land and Sea from 2006 to the present.

References

Abd IM (2005) Report on 2005 Fish Surveys in Iraq. Project Report. Baghdad, Iraq: Nature Iraq.

Abd IM (2006a) KBA Overview. Presentation to KBA Review Meeting. November 6–7, 2006. Damascus, Syria: Nature Iraq and BirdLife International.

Abd IM (2006b) Fish fauna of southern Iraq. Presentation to KBA Review Meeting. November 6–7, 2006. Damascus, Syria: Nature Iraq and BirdLife International.

Al-Daham NK (1982) The Ichthyofauna of Iraq and the Arab Gulf. Publication No. 1 (4). Basrah, Iraq: Basrah Natural History Museum. 102 p. (In Arabic).

Al-Daham NK (1988) Development of fishes in the marshes, south of Iraq – obstacles and solutions. The Arab Gulf 20(2): 85–97 (In Arabic).

Al-Hilli MR (1977) Studies on the plant ecology of the Ahwar region in southern Iraq. Ph.D. thesis. Cairo, Egypt: University of Cairo.

Al-Zubaidy AJM (1982) Ecological study on algae (phytoplankton) of the marshes near Qurna, southern Iraq. M.Sc. thesis. Basrah, Iraq: Basrah University. 95 p. (In Arabic).

Coad BW (1991) Fishes of the Tigris-Euphrates Basin: A critical check list. Syllogeus No. 68. 31 p.

Coad BW et al. In preparation. The Freshwater Fishes of Iraq. Ottawa, Canada: Canadian Museum of Nature.

Hussain NA, Saoud HA, Al Shami EJ (2008) Species composition and ecological indices of fishes in the restored marshes of southern Mesopotamia. Marsh Bulletin 3(1) (2008) 17–31.

IUCN (2009) The IUCN Red List of Threatened Species. Gland, Switzerland: The World Conservation Union (IUCN). See: http://www.iucnredlist.org.

Khalaf KT (1961) The Marine and Freshwater Fishes of Iraq. Baghdad, Iraq: Al-Rabitta Press. 164 p.

Mahdi N (1962) Fishes of Iraq. Baghdad, Iraq: Iraq Ministry of Education. 82 p.

Mohammed ARM (2007) Analysis of the fisheries of the Euphrates River, west Qurna, Basrah, Iraq. Proceedings of the Arabian Seas International Conference on Science and Technology of Aquaculture, Fisheries and Oceanography. 10–13 February 2007. Kuwait City, Kuwait.

Partow H (2001) The Mesopotamian Marshlands: Demise of an Ecosystem. Nairobi, Kenya: Division of Early Warning and Assessment, United Nations Environment Program.

Richardson CA, Hussain NA (2006) Restoring the Garden of Eden: an ecological assessment of the marshes of Iraq. BioScience 56(6): 477–489.

Rubec CDA, Bachmann A (2008) The Key Biodiversity Areas Program in Iraq: Objectives and Scope 2004–2008. Project Report. Sulaimani, Kurdistan, Iraq: Nature Iraq.

Rubec CDA, Coad BW (2007) Economic Importance and Proposed Conservation Priority for Iraq Fish Species. Paper prepared for the Canadian International Development Agency. Gatineau, Canada: Environment Canada and Canadian Museum of Nature.

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RESEARCH ARTICLE

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Structure and ecological indices of fish assemblages in the recently restored Al-Hammar Marsh, southern Iraq

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Abstract

The aim of the present study is to determine the species composition, the structure of the fish assemblages, and to develop ecological indices in the restored east Al-Hammar Marsh. Fish were collected from October 2005 to September 2006 at two stations (Mansoury and Burkah). Fish samples contained freshwater species, both native and alien, and marine species. Thirty-one species were collected, eleven of them marine, the rest freshwater. Native species numbered 14 (45%), alien species 6 (19%) and marine species 11 (36%). Resident species formed 32.2%, seasonal species 16.0% and occasional species 51.6% of the fauna. The abundance of species varied, *Liza abu* being the most dominant species, with *Carassius auratus* ranking second and *Acanthobrama marmid* ranking third, comprising 35.8%, 23.6% and 10.6% respectively. Ecological indices were as follows: diversity ranged from 1.07 in November to 2.01 in July, richness ranged from 0.74 in December to 2.83 in July, and evenness ranged from 0.48 in November to 0.84 in December. The highest monthly similarity was in May at 77% and lowest in December at 29%. Water temperature showed medium correlations (0.62 and 0.58) with both the number of species and the total catch, respectively, while salinity exhibited weak positive correlations (0.05 and 0.26) with both the number and the total catch of species, respectively. Temperature is related to species number, presumably as a surrogate for many other seasonal changes.

Keywords

Species composition, fish assemblage, ecological indices, tidal marsh diversity, Mesopotamian marshes, alien species, Iraq

Introduction

The marshes of southern Iraq were the largest wetlands in south-western Asia, covering more than 15,000 km^2 and representing about 44% of the inland freshwater bodies of Iraq. These marshes were a natural refuge for many aquatic organisms, especially fish and waterfowl. The environmental, hydrological and physiographical setting formed a unique ecosystem, allowing high biodiversity and richness of the aquatic biota. The marshes were also characterized by their productivity (Al-Hilli 1977, Al-Hilli et al. 2009, Al-Zubaidy 1985, Al-Mayah 1992) and consequently were the richest and rarest biotope in the region. The Mesopotamian marshes were considered by FAO (1999) as the major source of inland fisheries (60%) in Iraq, estimated at 23,600 tonnes (Partow 2001). They were the permanent habitat for millions of waterfowl and a flyway for millions more migrating between Siberia and Africa (Evans 2002).

Al-Hammar Marsh is situated south of the Euphrates River and extends from Nasiriyah City in the west of Iraq to the outskirts of Basrah City on the Shatt al-Arab River in the east. To the south is the saline-brackish Main Outfall Drainage (MOD) channel, sabkhas and the sand dune belt of the southern desert. The marsh area comprises 2800 km^2 of permanent marsh, expanding to over 4500 km^2 during the period of spring flooding and temporary inundation (Iraq Foundation 2003).

The formation of Al-Hammar Marsh was due to the deposition of the suspended load of the Tigris-Euphrates rivers and resulted in a shift from brackish lagoon and coastal marsh to inland marsh, occupied by fresh to brackish water (Aqrawi 1993, Aqrawi and Evans 1994).

Al-Hammar Marsh is the largest southern marsh extending through two provinces (Basrah and Nasiriyah). It is approximately 120 km long and 25 km wide. Maximum water depth in the marsh ranges from 1.8 m to 3.0 m. The marsh narrows about its middle, and consequently can be divided roughly into two parts, west and east, connected by a shallow channel (Fig. 1).

Planned drainage processes started in the early 1990s to divert the riverine water of the Tigris, Euphrates and Shatt al-Arab rivers away from the southern marshlands, resulting in a catastrophic loss of the native aquatic flora and fauna. In 2002, 93% of the permanent marshes defined in 1973 had been destroyed. Only 14.5% of the Al-Hammar Marsh remained (Richardson and Hussain 2006). Since 2003, great efforts have been made to restore the marshes and revive the wetlands environment. As of August 2007, the marshes had recovered almost 58% of their former area in 1972 according to UNEP/IMOS (2007).

After reflooding in April 2003, the west part of Al-Hammar Marsh was fed primarily from tributaries of the Euphrates, but the eastern part received a considerable amount of water from the Shatt al-Arab River, and groundwater recharge was another source of replenishment. The eastern part of Al-Hammar is a tidal marsh affected by the semi-diurnal tide from the Arabian Gulf, with well oxygenated oligohaline water, grey mud-silt sediments with low total organic carbon (TOC), and an alkaline pH (Hussain and Taher 2007, Tahir et al. 2008).

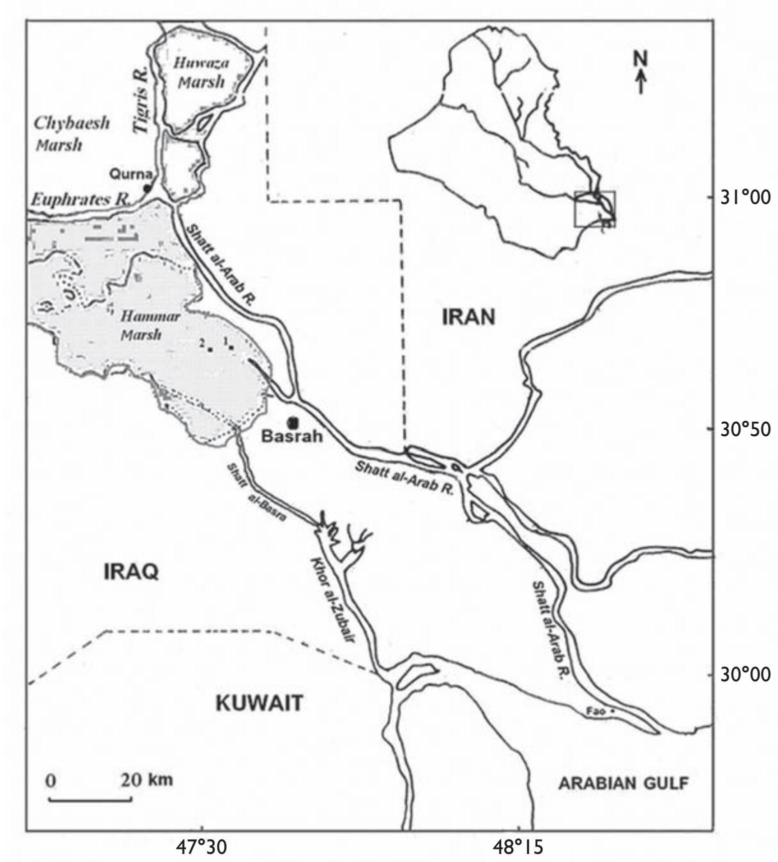

Figure 1. Map of southern of Iraq, showing the location of Al-Hammar Marsh (**1** Mansoury Site, **2** Burkah Site).

The structure of the fish assemblage in the southern marshes has not been studied. A few taxonomic works refer to the marshes in passing (Khalaf 1961, Mahdi 1962, Coad 1991) and recently reports on the environmental restoration of the southern marshes have appeared (e.g., IMRP 2006, ARDI 2006) along with articles concerned with the occurrence and biology of marine and diadromous fish (Mohamed et al. 2009). Most previous studies have focused on biological aspects of some of the freshwater fishes in Al-Hammar Marsh (Barak and Mohamed 1983, Dawood 1986, Jasim 1988, Al-Sayab 1989, Al-Kanaani 1989).

The aim of the present study is to determine the structure of the fish assemblage and the species composition in the restored Al-Hammar Marsh. Previously, no studies were conducted on the diversity of the fishes, taking into consideration their relative abundance, the monthly changes in ecological indices, and the similarity between sampled months coupled with the effects of environmental factors like water temperature and salinity.

Material and methods

From October 2005 to September 2006, fishes were collected monthly from two selected sites, both in east Al-Hammar: (1) Mansoury (30°40'32"N 47°37'21"E), environmentally considered as a tidal channel marsh and desiccated freshwater station, and (2) Burkah (30°40'22"N 47°33'03"E), a tidal open water marsh and desiccated station (Fig. 1). Sampling was carried out using a seine net (20 m long with a 2.5 cm mesh), fixed gill nets (50 m to 100 m long with 2.5 cm to 10 cm mesh size), and electro-fishing gear. Specimens were immediately transported to the laboratory on crushed ice. Water temperature and salinity were measured to determine the relationships of these two factors with the number of species and total catch of species. Fishes were identified to species by using Khalaf (1961), Mahdi (1962), Beckman (1962) and Coad (1991).

The ecological indices of the fish assemblage in east Al-Hammar Marsh, namely relative abundance, diversity, evenness, richness and similarity were calculated monthly according to Odum (1970), Shanon and Weaver (1949), Pielou (1977), Margalef (1968) and Boesch (1977), respectively. Fish species were divided into three categories according to their temporal occurrence in the monthly samples following Tyler (1971).

Results

Effects of abiotic factors

The monthly fluctuations in air and water temperatures and salinity in east Al-Hammar Marsh are illustrated in Fig. 2. Air temperature ranged from 15°C in February to 33°C in June and water temperature changed from 12.5°C in February to 29°C in July. The minimum value of salinity was 1.2 mg/l in August and the maximum value was 2.0 mg/l in May and July.

The relationships of water temperature and salinity with the total catch of individuals and the number of species in Al-Hammar Marsh are shown in Fig. 3. Water temperature showed a significant positive correlations with the number of species ($r = 0.620$, $p < 0.05$) and the total catch of fish individuals ($r = 0.578$, $p < 0.05$), while the salinity showed very weak positive correlations with both of them, $r = 0.056$ and $r = 0.262$, $p < 0.05$, respectively.

Species composition and temporal occurrence

The overall number of fish species caught from the marsh was 31, belonging to 14 families (Table 1). Cyprinidae, the dominant family in terms of number of species was represented by 12 species: *Aspius vorax, Carassius auratus, Barbus luteus, B. sharpeyi, B. xanthopterus, B. grypus, Cyprinus carpio, Ctenopharyngodon idella*, *Acanthobrama*

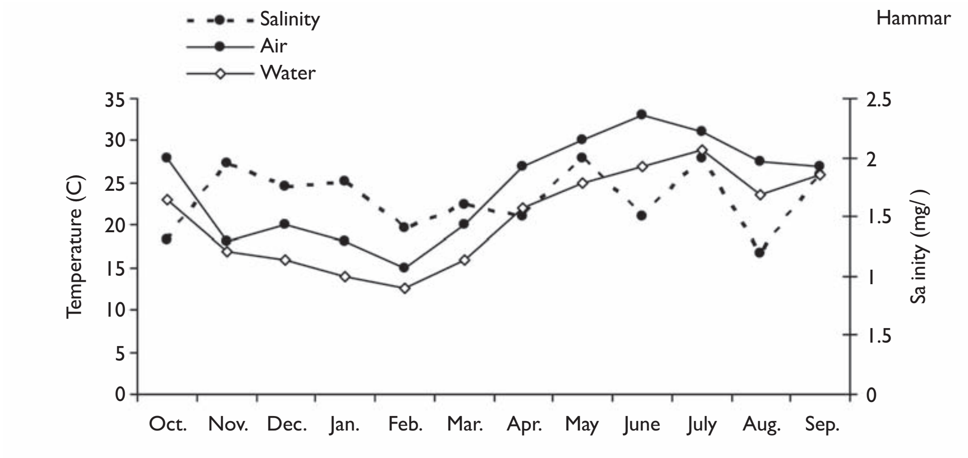

Figure 2. Monthly fluctuations in air, water temperature and salinity in east Al-Hammar Marsh (2005–2006).

marmid, Cyprinion macrostomum, Alburnus mossulensis, and *Alburnus* sp. Other species belonged to the families Mugilidae (*Liza abu*, *L. subviridis* and *L. klunzingeri*), Sparidae (*Acanthopagrus latus* and *A. berda*), Cyprinodontidae (*Aphanius dispar* and *A. mento*), Poeciliidae (*Gambusia holbrooki* and *Poecilia latipinna*), Gobiidae (*Bathygobius fuscus* and *Boleophthalmus dussumieri*), Clupeidae (*Tenualosa ilisha*), Siluridae (*Silurus triostegus*), Mastacembelidae (*Mastacembelus mastacembelus*), Heteropneustidae (*Heteropneustus fossilis*), Engraulidae (*Thryssa whiteheadi*), Scatophagidae (*Scatophagus argus*), Hemiramphidae (*Rhynchorhamphus georgii*), and Soleidae (*Brachirus orientalis*).

The fish fauna of eastern Al-Hammar Marsh may be broadly classified into three groups: native freshwater, alien and marine fish species. Fourteen native freshwater species (*Aspius vorax, Barbus luteus, B. sharpeyi, B. xanthopterus, B. grypus, Acanthobrama marmid, Alburnus mossulensis, Alburnus* sp., *Cyprinion macrostomum, Liza abu, Aphanius dispar, A. mento, Silurus triostegus* and *Mastacembelus mastacembelus*) constituted 45.1% of the total number of species. Six alien freshwater species (*Cyprinus carpio, Heteropneustus fossilis, Gambusia holbrooki, Carassius auratus, Ctenopharyngodon idella* and *Poecilia latipinna*) formed 19.4% of the total number of species. Eleven marine species (*Tenualosa ilisha, Liza subviridis, L. klunzingeri, Acanthopagrus latus, A. berda, Boleophthalmus dussumieri, Thryssa whiteheadi, Scatophagus argus*, *Bathygobius fuscus, Rhynchorhamphus georgii* and *Brachirus orientalis*) comprised 35.5% of the total number of species.

The monthly variations of native, alien and marine species in Al-Hammar Marsh are illustrated in Fig. 4. The highest numbers of total, native and marine species were in July and the lowest in December. There was a slight variation in the number of alien species throughout the year.

Species occurring temporally in the Al-Hammar Marsh were classified into three groups. The resident species were ten. Four of them appeared in all 12 months (*Liza abu, L. subviridis, Carassius auratus* and *Acanthobrama marmid*), one in 11 months

(*Barbus luteus*), four in 10 months (*Cyprinus carpio, Aspius vorax, Alburnus mossulensis* and *Heteropneustus fossilis*) and one in nine months (*Silurus triostegus*). The resident species, forming 32.3% of the total number, consisted of native, alien and marine species. Of the five seasonal species, *Thryssa whiteheadi* was captured in eight months and *Tenualosa ilisha* and *Barbus sharpeyi* in seven months, and the remaining two in six months (*Bathygobius fuscus* and *Aphanius dispar*). The seasonal species comprised 16.1% of the total number of species and the occasional species 51.6%. Sixteen species were categorized as occasional, two of them appeared in three months (*Aphanius mento* and *Cyprinion macrostomum*), two in two months (*Barbus xanthopterus* and *Acantho-*

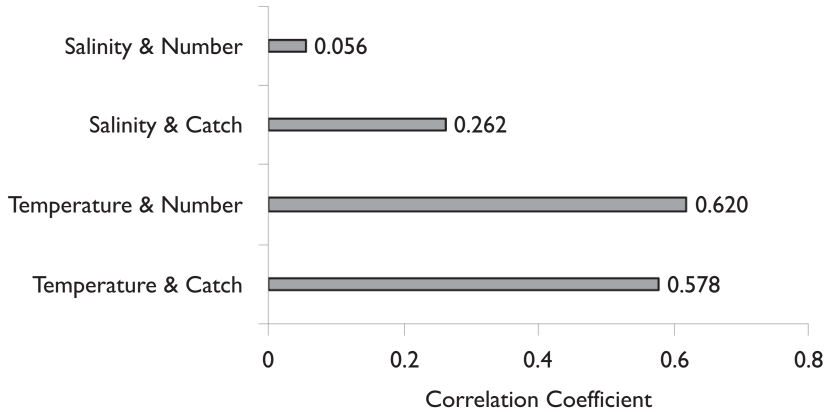

Figure 3. The relationships of water temperature and salinity with the total catch of individuals and the number of species in Al- Hammar Marsh

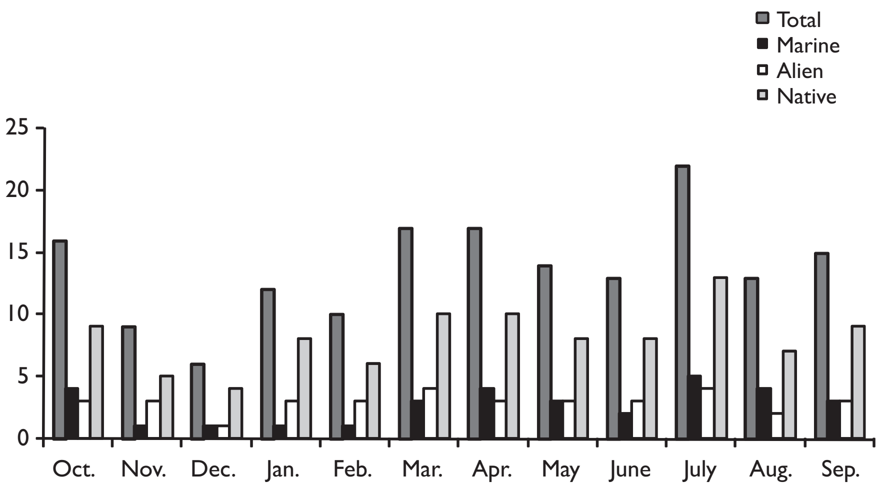

Figure 4. Monthly occurrence of total, native, alien and marine species in Al-Hammar Marsh

pagrus latus) and twelve in one month (*Barbus grypus, Mastacembelus mastacembelus, Boleophthalmus dussumieri, Scatophagus argus, Gambusia holbrooki, Ctenopharyngodon idella, Acanthopagrus berda, Rhynchorhamphus georgii, Poecilia latipinna, Brachirus orientalis, Liza klunzingeri* and *Alburnus* sp.).

The monthly variation of similarity of fish species composition in the marsh during the study period is shown in Fig. 5. The highest similarity level was found during May (77%) and the lowest during December (29%). Generally, the similarity level was high during the spring and summer months.

Relative abundance and ecological indices

A total of 16,199 fishes belonging to 31 species were collected from Al-Hammar Marsh, the highest number (2920) being in September and the lowest (800) in December. *Liza abu* was the most abundant species comprising 35.9% of the total number followed by *Carassius auratus* (23.6%), *Acanthobrama marmid* (10.8%) and *Tenualosa ilisha* (10.1%). The previous four species accounted for over 80% of the total catches. *Liza abu* was the dominant species throughout the year except October, with a peak in April. *Carassius auratus* was second in dominance (Table 1).

Monthly variations in ecological indices of species are illustrated in Fig. 6. The diversity index fluctuated from 1.07 in November to 2.01 in July, with an overall value of 1.53. The richness index ranged from 0.74 in December to 2.83 in July, with an overall value of 1.76. The evenness index ranged from 0.48 in November to 0.84 in December, with an overall value of 0.60.

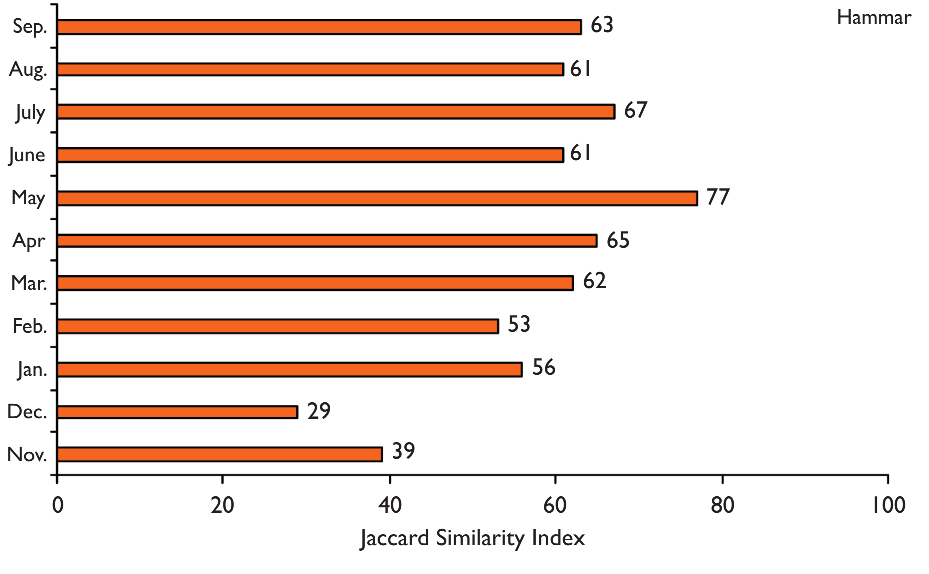

Figure 5. Monthly variations of similarity of species in Al-Hammar Marsh

Table 1. Monthly relative abundance (%) of fish species caught in the Al-Hammar Marsh.

Fish species	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Total
Liza abu	23.9	47.9	30.6	47.1	38.5	20.8	43.4	37.8	41.7	32.1	60.8	25.2	35.85
Carassius auratus +	42.8	41	20.5	28.7	23.5	18.9	28.6	21	34.5	23.8	15.4	6.4	23.6
Acanthobrama marmid	1.4	7.6	29	16	31.4	30.6	16.7	8.9	1.8	3.5	5.5	1.78	10.79
Tenualosa ilisha *	18.7					0.08	0.06	0.1		15.7	1.4	38.6	10.05
Thryssa whiteheadi *	3.2					0.3	0.12	0.7	0.4	1.9	8.7	14.9	3.79
Alburnus mossulensis	4.62	2	13.4	3.7	2	14.2	1.59	3.4	1.1	0.78		3.79	3.9
Cyprinus carpio +	0.17			0.2	0.1	0.3	0.29	17.2	11.1	3.2	0.9	0.7	2.86
Aspius vorax	0.3	0.09		0.2		0.38	0.77	3.9	6.1	1.34	2.3	2.8	1.78
Barbus luteus	0.3		0.3	0.2	1.5	0.84	1.4	2.5	1.1	3.8	3.6	2.2	1.65
Liza subviridis *	3.7	0.2	6.3	2.2	1.6	2.4	1.4	0.2	0.9	0.6	0.49	1.6	1.63
Silurus triostegus	0.3	1.1				0.76	1.95	3.2	0.3	0.42	0.6	0.27	0.76
Heteropneustus fossilis +	0.08	0.09		0.2	0.6	3.04	2.48	0.5	0.7	0.12		0.03	0.68
Poecilia latipinna +										6			0.62
Cyprinion macrostomum										4.3	0.2	0.03	0.46
Aphanius dispar	0.08			0.3	0.5	4		0.2		0.06			0.4
Boleophthalmus dussumieri *	0.08												0.006
Aphanius mento						3.12	0.24		0.4				0.31
Alburnus sp.												1.5	0.27
Bathygobius fuscus *	0.08			0.2			0.94	0.4	0.1	0.06			0.17
Barbus sharpeyi	0.08				0.3	0.08	0.06			0.7	0.1	0.2	0.15
Acanthopagrus latus *							0.06			1.1			0.12
Barbus grypus										0.2			0.05
Mastacembelus mastacembelus				0.8									0.05
Barbus xanthopterus						0.15				0.06			0.02
Liza klunzingeri *										0.18			0.02
Scatophagus argus *	0.08												0.006
Gambusia holbrooki +						0.08							0.006
Ctenopharyngdon idella +		0.09											0.006
Acanthopagrus berda *											0.1		0.006
Rhynchorhampus georgii *							0.06						0.006
Brachirus orientalis *										0.06			0.006
Total No. fish													16199

* Marine species + Alien species

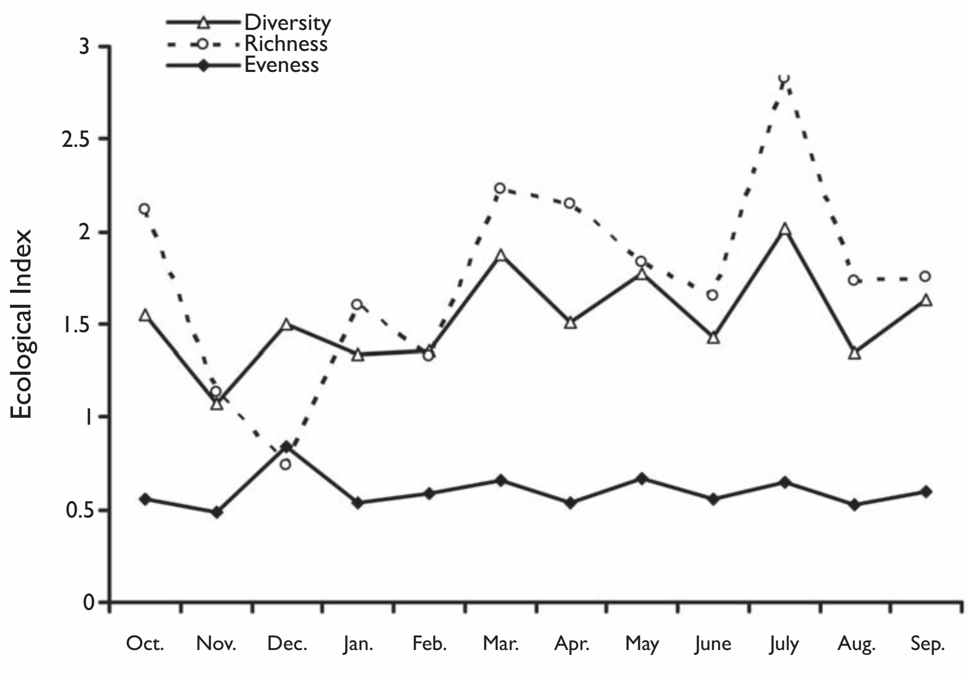

Figure 6. Monthly variations in ecological indices of fish species composition in Al-Hammar Marsh.

Discussion

Coad (1991) gave the total number of fishes in fresh waters of Iraq as 58 consisting of 43 freshwater, eight marine and seven exotic species. The number of species collected from the restored Al-Hammar Marsh was 31, nearly similar to a previous estimate by Al-Daham (1982) at 33 for all southern marshes. However, the species constitution was different from historical observations, several freshwater species having disappeared due to the long desiccation and degradation of the Al-Hammar environment, and the numbers being added to by more alien and marine species (Khalaf 1961, Mahdi 1962).

The deterioration of water quality of the Al-Hammar Marsh led to several cyprinid species disappearing even before the desiccation, e.g., *Barbus subquincunciatus* and *B. scheich*, which disappeared due to an increase in salinity from 0.4g/l in the 1970s (Al-Saadi et al. 1981) to 6.3g/l in the early 1990s (Al-Rikabi 1992). After inundation in 2003, a few native species substantially decreased in number, e.g., *Barbus xanthopterus* and *B. grypus* with very low relative abundance 0.02% and 0.05% respectively, due to scarcity of benthic food resources (insects and mollusks), competition with the alien species *Cyprinus carpio* (Al-Kanaani 1989), and increased salinity. Other native species became rare due to the loss of their habitat to the introduced species, e.g., *Barbus sharpeyi* to *Ctenopharyngodon idella* and *Barbus luteus* to *Carassius auratus* as indicated by their low abundance (Richardson 2008, Barak and Mohamed 1983, Jasim 1988). In general, the freshwater species composition of Al-Hammar Marsh was similar to other southern Iraqi marshes indicating that desiccation altered the fish composition in all southern marshes (Hussain et al. 2008, Richardson 2008).

The most abundant species in Al-Hammar, *Liza abu, Carassius auratus* and *Acanthobrama marmid*, were identical to other southern marshes because the ichthyofauna was originally derived from the Tigris, Euphrates and Shatt al-Arab rivers. The major difference was the seasonal occurrence of marine species in the Al-Hammar Marsh, but not in other southern marshes (CIMI 2006). The abundance of marine species led to an increase in richness, evenness and diversity indices and created seasonal fluctuation in relative abundance and total number of individuals in comparison with other freshwater marshes of southern Iraq (Hussain et al. 2006, Richardson 2008).

Because of the lack of data on the marshes before desiccation, comparisons were made with studies on other Iraqi lakes and reservoirs. During the 1980s, Epler et al. (2001) found in Habbaniyah, Tharthar and Razzazah lakes (central Iraq) that *Liza abu* was the most abundant species followed by *Alburnus mossulensis*. In the late 1990s, Al-Rudainy et al. (1999, 2001) showed that the fish assemblages in Habbaniyah Lake and Al-Qadisiya Reservoir (western Iraq) were also dominated by *Liza abu* and *Carassius auratus*, similar to the situation in Al-Hammar Marsh and other southern marshes (Hussain et al. 2006, 2008; Mohamed et al. 2009).

Higher diversity and richness in the eastern Al-Hammar Marsh during summer (July) could be due to recruitment of resident species after spring spawning (Ahmed et al. 1984, Dawood 1986, Jasim 1988, Naama et al. 1986), more individuals brought with the spring flood from the Euphrates River, and to the penetration of marine species especially anadromous ones such as *Tenualosa ilisha* and *Liza subviridis*. Emigration of marine species back to the Shatt al-Arab Estuary and the Arabian Gulf in winter (December) (Mohamed et al. 2009), led to higher evenness values and return of the fish assemblage to its stable state consisting of resident freshwater species during winter and early spring. Monthly similarity was the highest in May (77%), coinciding with the gathering of many freshwater species for spawning. The September peak in total number of individuals was due to an increase in number of *T. ilisha* juveniles (Mohamed et al. 2009).

Temperature has a stronger correlation with number of species and the total number of individuals (catch) than salinity. Increase of temperature in spring and summer accelerated the productivity cycle of plankton and also decomposition rates of organic materials, i.e. more food resources become available for fish (Hammadi et al. 2007, Al-Sodani et al. 2007). The same conclusion was reached for the Khor Al-Zubair lagoon by Ali and Hussain (1990), reflecting that temperature was more related to species abundance than salinity in this tidal marsh. Temperature also clearly relates to seasonal patterns within southern Iraq.

The seasonal existence of marine species indicates that the restored Al-Hammar Marsh plays a vital part in the recovery of fisheries (*Tenualosa ilisha, Liza subviridis,* *L. klunzingeri* and the shrimp *Metapenaeus affinis*) of the north-western Arabian Gulf after becoming noticeably degraded during the period of desiccation of the Al-Hammar Marsh in the 1990s. Al-Yamani et al. (2007) indicated a close interrelationship between the southern Iraqi marshes and the environment of the north-western Arabian Gulf.

It seems that the restored Al-Hammar Marsh plays a role as a feeding and nursery ground for juveniles of marine species like *Tenualosa ilisha, Liza subviridis* and *Thryssa whiteheadi*, thick submergent plants like *Ceratophyllum demersum* offering a suitable cover from predatory fishes like *Aspius vorax and Silurus triostegus,* and from waterfowl. Globally, tidal marshes have a higher biological productivity than other freshwater marshes and offer protection from large marine predators.

The extreme dessciation of the marshes of southern Iraq in August 2009, as evidenced by satellite imagery, has destroyed the role of this marsh in the ecology of the fish fauna. It may still recover again if climate improves and a sufficient supply of water is released from upriver countries.

Acknowledgements

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References

Ahmed HA, Al-Mukhtar MA, Al-Adhub AHY (1984) The reproductive biology of *Carasobarbus luteus* (Pisces, Cyprinidae) in Al-Hammar Marsh, Iraq. *Cybium* 8(4): 69–80.

Al-Daham NK (1982) The ichthyofauna of Iraq and the Arab Gulf. A check-list. *Publications of the Basrah Natural History Museum* 4: 120 pp.

Al-Hilli MR (1977) Studies on the plant ecology of the Ahwar region in southern Iraq. *PhD thesis*, Cairo: University of Cairo.

Al-Hilli MRA, Warner BG, Asuda T, Douabul A (2009) An assessment of vegetation and environmental controls in the1970s of the Mesopotamian wetlands of southern Iraq. *Wetlands Ecology and Management* (in press).

Ali TS, Hussain NA (1990) Composition and seasonal fluctuations of intertidal fish assemblage in Khor Al- Zubair, Northwestern Arabian Gulf, Iraq. *Journal of Applied Ichthyology* 6: 24–34.

Al-Kanaani SM (1989) Diet overlap among the common carp Cyprinus carpio L. and three native fish species in Al-Hammar marshes, southern Iraq. *MSc. thesis*, Basrah: Basrah University. 118 pp.

Al-Mayah AA (1992) Aquatic plants in marshes of south of Iraq, p. 127–148, *in* Hussain NA (Ed). *Ahwar of Iraq: An environmental Approach*. Marine Science Center Publication, University of Basrah 18: 299 pp.

Al-Rikabi HUK (1992) An ecological and physiological study for some aquatic plants in Al-Hammar Marsh. *MSc thesis*, Basrah: Basrah University.

Al-Rudainy AJ, Mosa KM, Abulhani A, Ruhaij AM, Ali HA (2001) Some biological aspects of fishes collected from Al-Maathide and Beajan regions in Al-Qadisiya dam lake. *Scientific Journal of the Iraqi Atomic Energy Commission* 3(1): 26–39.

Al-Rudainy AJ, Ruhiage AM, Qatee AJ, Hussein TS (1999) Some biological aspects of fishes collected from Al-Habbaniya Lake. *Iraqi Journal of Agriculture (Special Issue)* 4(5): 159–167.

Al-Saadi HA, Antoine SE,.Nurul Islam AKM (1981) Limnological investigation in Al-Hammar Marsh area in Southern Iraq. *Nova Hedwigia.* 35: 157–166.

Al-Sayab AAZ (1989) Ecology and Biology of the Asiatic catfish Silurus triostegus Heckel, 1843, Pisces Siluridae from Al-Hammar marshes southern Iraq. *MSc. thesis*, Basrah: Basrah University. 121 pp.

Al-Sodani HM, Abed JM, Al-Essa SAK, Hammadi NS (2007) Quantitative and qualitative study on zooplankton in restored southern Iraqi marshes. *Marsh Bulletin* 2: 43–63.

Al-Yamani FY, Bishop JM, Al-Rifaie K, Isamail W (2007) The effects of the river diversion, Mesopotamian marsh drainage and river damming on the marine environment of the northwestern Arabian Gulf. *Aquatic Ecosystem Health and Management* 10(3): 277–289.

Al-Zubaidy AJM (1985) Ecological study on Algae (Phytoplankton) to the marshes near Qurna, Southern Iraq. *MSc thesis*, Basrah: Basrah University. 95 pp.

Aqrawi AAM (1993) Implications of sea–level fluctuations, sedimentation an neotectonics for the evolution of the marshlands (Ahwar) of southern Mesopotamia. *Quaternary Proceedings* 3:17–26.

Aqrawi AAM, Evans G (1994) Sedimentation in the lakes and marshes (Ahwar) of the Tigris-Euphrates delta, southern Mesopotamia. *Sedimentology* 41(4): 755–776.

ARDI (2006) *Marshlands monitoring*. Final report, Development Alternative International, Agriculture Reconstruction and Development Program for Iraq (ARDI), U.S. Agency for International Development, Washington. 172 pp.

Barak NAA, Mohamed ARM (1983) Biological study of the cyprinid fish, *Barbus luteus* (Heckel) in Garma Marshes. *Journal of Biological Sciences Research, Baghdad* 14(2): 53–70.

Beckman WC (1962) The freshwater fishes of Syria and their general biology and management. *Food and Agriculture Organization, Rome, Fisheries Biology Technical Paper* 8: v + 297 pp.

Boesch DF (1977) Application of numerical classification in ecological investigations of water pollution. *U.S. Environmental Protection Agency Ecological Research Series*, EPA-600/3-77-033, Corvallis, Oregon. Ix + 115 pp.

CIMI (2006) Species composition, ecological indices, length frequency and food habits of fish assemblages of the restored southern Iraqi marshes. Fish Ecology Report, Canadian-Iraqi Marshes Initiative (CIMI). 172 pp.

Coad BW (1991) Fishes of the Tigris–Euphrates Basin: A Critical Checklist. *Syllogeus, Ottawa* 68: 49 pp.

Dawood AH (1986) The biology of common carp (Cyprinus carpio) in Hor Al-Hammar marsh, southern Iraq. *MSc thesis*, Basrah: University of Basrah. 94 pp.

Epler P, Bartal R, Szczerbowski JA, Szypula J (2001) The ichthyofauna of lakes Habbaniya, Tharthar and Razzazah. *Archiwum Rybactwa Polskiego* 9(supplement 1): 171–184.

Evans MI (2002) The Ecosystem, p. 201–219 *in* Nicholson E, Clark P (Eds). *The Iraqi Marshlands: A Human and Environmental Study.* The Amar International Charitable Foundation, London. Xv + 332 pp.

FAO (1999) Fishery country profile. FID/CP/IRQ Rev. 2.

Hammadi NS, Jasim AQ, Al-Sodani HM (2007) Occurrence and seasonal variations of phytoplankton in the restored marshes of southern Iraq. *Marsh Bulletin* 2: 96–109.

Hussain NA, Mohamed ARM, Al-Noor SA, Coad B, Mutlak FM, Ibrahem M, Al-Sudani IM, Mojer AM, Toman AJ, Abdad MA (2006) Species composition, ecological indices, length frequencies and food habits of fish assemblages of the restored southern Iraqi marshes. Annual final fish report. Basrah University, Iraq and Waterloo University, Canada. 114 pp.

Hussain NA, Saoud HA, Al-Shami EJ (2008) Species composition and ecological indices of fishes in the restored marshes of southern Mesopotamia. *Marsh Bulletin* 3:17–31.

Hussain NA, Taher MA (2007) Effect of daily variations, diurnal fluctuations and tidal stage on water parameters of East Hammar marshland, Southern Iraq. *Marsh Bulletin* 2: 32–42.

IMRP (2006) Monitor marsh ecosystem recovery. Iraq Marshlands Restoration Program (IMRP), Final Report, USAID/ Development Alternative Inc. 528 pp.

Iraq Foundation (2003) Physical characteristic of Mesopotamian marshlands of southern Iraq. Draft report, Iraq Foundation. 45 pp.

Jasim AAW (1988) Reproductive biology of Barbus sharpeyi Gunther 1874 (Pisces, Cyprinidae) south Al-Hammar marsh, Iraq. *MSc thesis*, Basrah: University of Basrah. 89 pp.

Khalaf KT (1961) The marine and fresh water fishes of Iraq. Ar-Rabitta Press, Baghdad. 164 pp.

Mahdi N (1962) Fishes of Iraq. Ministry of Education, Baghdad. 82 pp.

Margalef R (1968) Perspectives in ecological theory. University of Chicago Press. 111 pp.

Mohamed ARM., Hussain NA., Al-Noor SS, Coad B., and Mutlak FM (2009) Status of diadromous fish species in the restored East Hammar marsh in southern Iraq, p. 577–588. In: Haro AJ, Smith KL, Rulifson RA, Moffitt CM, Klauda RJ, Dadswell MJ, Cunjak RA, Cooper JE, Beal KL and Avery TS (Eds.). 2nd International Symposium on Diadromous Fishes, Challenges for Diadromous Fishes in a Dynamic Global Environment, 18–22 June 2007, Halifax, Nova Scotia, Canada, American Fisheries Society Symposium 69: 943 pp.

Naama AK, Ahmed HA, Al-Adhub AHY (1986) Aspects of reproduction of the mullet *Liza abu* (Heckel) (Pisces, Mugilidae) in Al-Hammar Marsh, Iraq. *Cybium* 10(1): 47–55.

Odum WE (1970) Insidious alteration of the estuarine environment. *Transactions of the American Fisheries Society* 99: 836–847.

Partow H (2001) The Mesopotamian Marshlands: Demise of an Ecosystem. Early Warning and Assessment Technical Report, United Nations Environment Programme, Nairobi, NEP/DEWA/TR.01-3 Rev. 1:x + 47 pp.

Pielou EC (1977) Mathematical ecology. John Wiley, New York. 386 pp.

Richardson CJ (2008) Wetlands of mass destruction: can the garden of Eden be fully restored? *National Wetlands Newsletter* 30: 2–7.

Richardson CJ Hussain NA (2006) Restoring the Garden of Eden: An ecological assessment of the marshes of Iraq. *BioScience* 56(6): 477–489.

Shanon CE Weaver W (1949) The Mathematical Theory of Communication. University of Illinois Press, Urbana. 117 pp.

Tahir MA, Risen AK, Hussain NA (2008) Monthly variations in the physical and chemical properties of the restored southern Iraq marshes. *Marsh Bulletin* 3: 81–94.

Tyler AV (1971) Periodic and resident components in communities of Atlantic fishes. *Journal of the Fisheries Research Board of Canada* 28(7): 935-946.

UNEP/IMOS (2007) Iraqi marshland observation system. United Nations Environmental Programme, Iraqi Marshlands Observation System, http://imos.grid.unep.ch.

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RESEARCH ARTICLE

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Key Biodiversity Areas: Rapid assessment of birds in Kurdistan, northern Iraq

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Abstract

Bird surveys to help identify and assess Key Biodiversity Areas (KBAs) were undertaken in Kurdistan in the winter and summer of 2008. The winter survey was from 19 January to 8 February and the summer survey from 7 May to 16 June, a total of 45 days. During these periods a total of 34 sites were surveyed in the North Iraq governorates of Sulaimani, Erbil, and Dohuk and 185 species of birds recorded. Of these, according to IUCN criteria, one species was globally endangered, three vulnerable and two near threatened. In addition, 32 species were considered to be of conservation concern in Iraq, based on a system developed by Richard Porter. Of the species observed, 124 were confirmed or probable breeding, whilst 59 were winter visitors. The KBA selection process used the Middle East Important Bird Areas (IBAs) criteria, which considers seven species-based categories.

Keywords

Key Biodiversity Areas, birds, Kurdistan, Iraq

Introduction

Kurdistan is located between 42°20' – 45°15' longitude and 37°23' – 34°20' latitude. It covers 65000 km², approximately 15% of the total area of Iraq. Biogeographically, it lies in the Irano-Tauranian region (Irano-Anatolian sub-region) in the southeast of the western Palearctic realm, which consists mainly of mountainous areas in inner Anatolia and Armenia, the Iranian mountain plateau, and the greater part of Transcaspia (Eken et al. 2004).

In the past, limited surveys have been carried out in Iraqi Kurdistan. They revealed the presence of many areas important to birds. The aim of this study was to identify the Key Biodiversity Areas (KBAs) by surveying the bird populations and determining the trigger bird species. These are birds of global and/or regional importance from a conservation point of view, based on IUCN (2001) categories of Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concerned (LC), and Conservation Concern (CC), an additional category specific to Iraq, which is defined below.

The KBA selection process uses the Middle Eastern Important Bird Areas (IBAs) criteria, defined by BirdLife International (Evans 1994):

A: Important Bird Areas - Global importance
- A1. Species of global conservation concern
- A2. Restricted-range species
- A3. Biome-restricted species
- A4. Congregations

B: Important Bird Areas - Middle Eastern importance
- B1: Regionally important congregations
- B2: Species with an unfavorable conservation status in the Middle East
- B3: Species with a favorable conservation status but concentrated in the Middle East

There are over 835 species of birds in the Middle East (Porter & Aspinall in prep.) of which over 400 have been recorded in Iraq (Salim et al. 2006). In the 2008 surveys in Kurdistan 185 species were observed.

Materials and methods

Bird observations were made using 8×42 Minox binoculars, a Canon 5D digital camera with 100–400 Sigma lens, and Kawa 500 mm spotting scopes (TSN-601). Depending on the type of sites visited, point, area and/or transect counts were taken at each site. All species were counted. This was often done from fixed points, e.g. when counting waterfowl on large lakes or seaching for raptors in the mountains, but more frequently it involved a transect through the main habitats, along which all birds were counted. Species were identified using Salim et al. (2006); Porter et al. (1996); and Mullarney et al. (1999). The study was carried out at 34 sites in Sulaimani, Erbil, and Dohuk Governorates. Lake sites visited included: Darbandikhan Lake (S1), Dukan Lake (S2), Mosul Lake (D10), and Duhok Lake (D9). Watered valleys and gorge sites included Ahmad Awa (S4A), Awesar (S4B), Sargalu (S7), Chami Razan (S10), Penjween (S5), Haji Omran (E1), Smaquly and Ashaba Valley (E5A and E5B), Bakhma on the Big Zap River (E7), Barzan Area (E8), Kherazook (E9), Gali Zanta and Garbeesh (D1A and D1B), Ser Amadia and Sulav (D2A and D2B), Atrush (D3), Garagu (D5), Benavi (D6), and Sararu (D13). Mountainous areas with oak and/or pine forest sites included: Peramagroon Mountain (S6), Qara Dagh (S11), Sharbazher Area (S13), Zawita (D7), Mangesh (D8). Lowland sites with farmlands and foothills where: Chamchamal (S9), Zalm Area (S12), Sangaw (S14), Turaq Steppe (E4), Kalakchi and Khazar (D12A and D12 B). One marshland site, Altun Kopri on the Little Zap River (E3), was also visited. Lastly several wide and open rivers and their environs were included such as Kalar on the Diyala River (S3), Aski Kalak on the Big Zap River (E10), Taq Taq on the Little Zap River (E2), Bahraka on the Big Zap River (E11), and Fishkhaboor on the Tigris River (D11) (Fig. 1).

Results and discussion

In January and February [Winter (W)] 2008 and May and June [Summer (S)] 2008, 185 bird species belonging to 49 families were recorded in the areas surveyed (Table 1). Six bird species were considered VU: *Aquila heliaca*, *Anser erythropus*, and *Falco naumani;* EN: *Neophron percnopterus*, NT: *Coracias garrulus* and *Emberiza cineracea*; and 32 species were categorized CC.

Conservation Concern (CC): The definition has been developed by Richard Porter in conjunction with staff members of Nature Iraq, in an attempt to determine those species for which Iraq has a special responsibility and which are a priority for conservation action. Species of the CC category include all globally threatened species; Iraqi endemics and near-endemics; those known to be seriously declining throughout or in most of their Eurasian/Middle Eastern range of distribution; those with a major

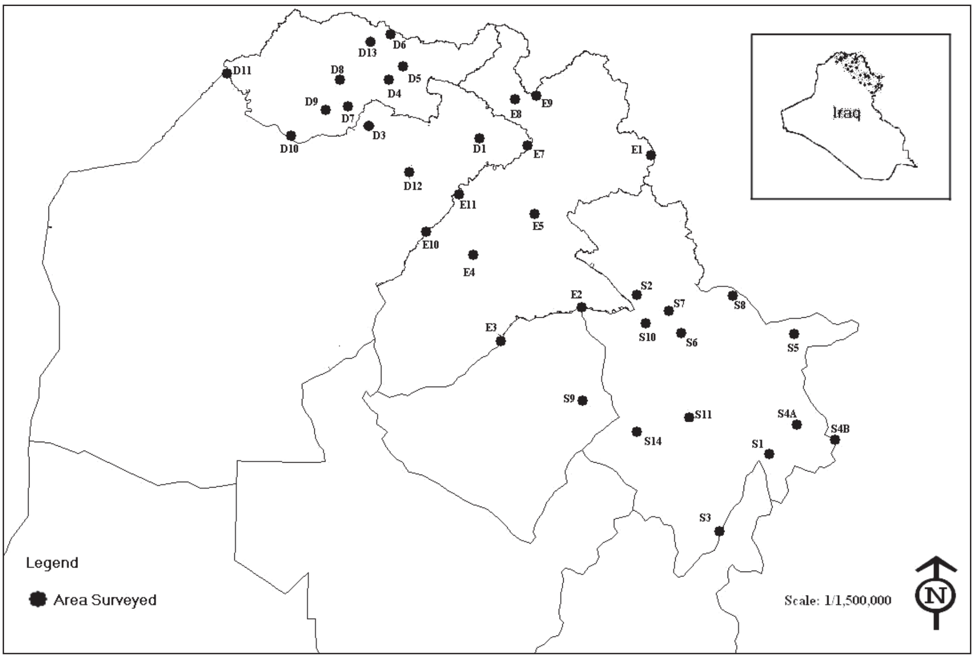

Figure 1. Map of areas surveyed.

Table 1. Status of birds recorded in Kurdistan, northern Iraq during the 2008 surveys, showing IUCN conservation status as evaluated by BirdLife International: LC (Least Concern), NT (Near Threatened), VU (Vulnerable), EN (Endangered), CC (Conservation Concern)].

Bird Species Name	Scientific Name	Conservation Status	Winter Survey	Summer Survey	Migration Status
Family: Phasianidae					
Chukar Partridge	*Alectoris chukar*	LC		X	resident breeder
See-see Partridge	*Ammoperdix griseogularis*	LC	X	X	resident breeder
Black Francolin	*Francolinus francolinus*	LC	X		resident breeder
Common Quail	*Coturnix coturnix*	LC	X		passage migrant; breeding summer visitor
Family: Anatidae					
Greylag Goose	*Anser anser*	LC	X	X	winter visitor, some may breed
Greater White-fronted Goose	*Anser albifrons*	LC	X		winter visitor
Lesser White-fronted Goose	*Anser erythropus*	VU, CC	X		winter visitor
Common Shelduck	*Tadorna tadorna*	LC	X		winter visitor
Ruddy Shelduck	*Tadorna ferruginea*	LC	X		resident; winter visitor and passage migrant
Mallard	*Anas platyrhynchos*	LC	X	X	winter visitor; passage migrant and some may breed
Eurasian Teal	*Anas crecca*	LC	X		winter visitor and passage migrant
Common Pochard	*Aythya ferina*	LC	X		winter visitor
Red-crested Pochard	*Netta rufina*	CC	X		winter visitor and passage migrant
Tufted Duck	*Aythya fuligula*	LC	X		winter visitor
Goldeneye	*Bucephala clangula*	LC	X		winter visitor
Smew	*Mergellus albellus*	LC	X		winter visitor
Little Grebe	*Tachybaptus ruficollis*	CC		X	resident breeder; winter visitor and passage migrant
Great Crested Grebe	*Podiceps cristatus*	LC	X		resident; winter visitor
Black-necked Grebe	*Podiceps nigricollis*	LC	X		resident; winter visitor
Family: Ciconiidae					
Western White Stork	*Ciconia ciconia*	LC	X	X	passage migrant; breeding summer visitor, but the first flock observed on 19th January 2008

Bird Species Name	Scientific Name	Conservation Status	Winter Survey	Summer Survey	Migration Status
Family: Threskiornithidae					
Eurasian Spoonbill	*Platalea leucorodia*	CC		X	resident; breeding summer visitor; passage migrant
Family: Ardeidae					
Little Bittern	*Ixobrychus inutes*	LC		X	breeding summer visitor; passage migrant; some winter visitor.
Black-crowned Night Heron	*Nycticorax nycticorax*	LC	X	X	resident; breeding summer visitor; passage migrant
Squacco Heron	*Ardeola ralloides*	LC		X	resident; breeding summer visitor; and passage migrant
Grey Heron	*Ardea cinerea*	LC	X	X	winter visitor, passage migrant and some may breed
Great White Egret	*Ardea [Egretta] alba*	LC	X		winter visitor and passage migrant
Little Egret	*Egretta garzetta*	LC	X	X	winter visitor; passage migrant and some may breed
Family: Phalacrocoracidae					
Pygmy Cormorant	*Phalacrocorax pygmaeus*	CC	X		winter visitor, and passage migrant
Great Cormorant	*Phalacrocorax carbo*	LC	X	X	winter visitor and passage migrant
Family: Falconidae					
Lesser Kestrel	*Falco naumani*	VU, CC		X	passage migrant, and breeding summer visitor
Common Kestrel	*Falco tinnunculus*	LC	X	X	resident breeder; winter visitor.
Eurasian Hobby	*Falco subbuteo*	LC		X	breeding summer visitor; passage migrant
Barbary Falcon	*Falco pelegrinoides*	LC		X	resident breeder; winter visitor
Family: Accipitridae					
Black Kite	*Milvus migrans*	LC		X	winter visitor, passage migrant, and some may breed
Lammergeier	*Gypaetus barbatus*	CC	X	X	resident breeder; winter visitor
Egyptian Vulture	*Neophron percnopterus*	EN, CC		X	breeding summer visitor; passage migrant
Eurasian Griffon Vulture	*Gyps fulvus*	LC	X	X	resident breeder; winter visitor

Bird Species Name	Scientific Name	Conservation Status	Winter Survey	Summer Survey	Migration Status
Short-toed Snake Eagle	*Circaetus gallicus*	LC		X	breeding summer visitor, and passage migrant
Western Marsh Harrier	*Circus aeruginosus*	LC	X	X	winter visitor, and some may breed
Hen Harrier	*Circus Cyaneus*	LC	X		winter visitor
Eurasian Sparrowhawk	*Accipiter nisus*	LC	X	X	winter visitor, and passage migrant
Levant Sparrowhawk	*Accipiter brevipes*	CC		X	passage migrant, and may breed
Steppe Buzzard	*Buteo b. vulpinus*	LC	X	X	resident breeder; winter visitor and passage migrant
Long-legged Buzzard	*Buteo rufinus*	LC	X	X	resident breeder; winter visitor and passage migrant
Steppe Eagle	*Aquila nipalensis*	CC	X		winter visitor; passage migrant
Asian Imperial Eagle	*Aquila heliaca*	VU, CC	X		winter visitor and passage migrant
Golden Eagle	*Aquila chrysaetos*	CC	X	X	resident; winter visitor
Booted Eagle	*Aquila [Hieraaetus] pennata[pennatus]*	LC		X	breeding summer visitor; passage migrant
Bonelli's Eagle	*Aquila [Hieraaetus] fasciata [fasciatus]*	LC		X	resident breeder
Family: Rallidae					
Water Rail	*Rallus aquaticus*	LC		X	winter visitor and passage migrant
Common Moorhen	*Gallinuylua chloropus*	LC	X	X	resident breeder; winter visitor and passage migrant
Eurasian Coot	*Fulica atra*	LC	X		winter visitor; passage migrant and some may breed
Family: Haematopodidae					
Eurasian Oystercatcher	*Haematopus ostralegus*	LC		X	winter visitor and passage migrant
Family: Recurvirostridae					
Black-winged Stilt	*Himantopus ostralegu*	LC	X	X	resident breeder; winter visitor and passage migrant
Family: Charadriidae					
Northern Lapwing	*Vanellus vanellus*	LC	X		winter visitor, and some may breed
Spur-winged Lapwing	*Vanellus (Hoplopterus) spinosus*	CC		X	resident breeder; passage migrant

Bird Species Name	Scientific Name	Conservation Status	Winter Survey	Summer Survey	Migration Status
Red-wattled lapwing	*Vanellus (Hoplopterus) indicus*	LC	X	X	resident breeder
White-tailed Lapwing	*Vanellus leucurus*	CC		X	resident breeder; probably winter visitor
Little-ringed Plover	*Charadrius dubius*	LC	X	X	resident breeder, and passage migrant
Family: Scolopacidae					
Common Snipe	*Callinago callinago*	LC	X	X	winter visitor, and passage migrant
Common Redshank	*Tringa tetanus*	LC	X		winter visitor, passage migrant
Common Greenshank	*Tringa nebularia*	LC	X		passage migrant & winter visitor
Green Sandpiper	*Tringa ochropus*	LC		X	winter visitor, and passage migrant
Common Sandpiper	*Actitis hypoleucos*	LC		X	passage migrant, and breeding summer visitor
Family: Gareolida					
Collared Pratincole	*Glareola pratincola*	CC		X	passage migrant, and breeding summer visitor
Family: Laridae					
Common Gull	*Larus canus*	LC	X		winter visitor
Yellow-legged Gull	*Larus michahellis*	LC	X		winter visitor
Armenian Gull	*Larus armenicus*	CC	X	X	winter visitor, and passage migrant
Great Black-headed Gull	*Larus ichthyaetus*	LC	X		winter visitor
Common Black-headed Gull	*Larus ridibundus*	LC	X	X	winter visitor, and some may breed
Slender-billed Gull	*Larus genei*	CC	X	X	resident; breeding summer visitor; winter visitor and passage migrant
Gull-billed Tern	*Gelochelidon [Sterna] nilotica*	LC		X	breeding summer visitor, and passage migrant
Common Tern	*Sterna hirundo*	LC		X	breeding summer visitor, and passage migrant
White-winged Tern	*Chlidonias leucopterus*	LC		X	summer visitor; may breed, and passage migrant
Family: Pteroclididae					
Pin-tailed Sandgrouse	*Pterocles alchata*	CC		X	breeding resident; nomadic

Bird Species Name	Scientific Name	Conservation Status	Winter Survey	Summer Survey	Migration Status
Black-bellied Sandgrouse	*Pterocles orientalis*	LC		X	winter visitor and passage migrant
Family: Columbidae					
Rock Dove	*Columba livia*	LC	X	X	resident breeder
Common Woodpigeon	*Columba palumbus*	LC	X	X	resident breeder; winter visitor
European Turtle Dove	*Streptopelia turtur*	CC		X	passage migrant, breeding summer visitor
Eurasian Collared Dove	*Streptopelia decaocto*	LC	X	X	resident breeder
Laughing Dove	*Streptopelia senegalensis*	LC	X	X	resident breeder
Family: Cuculidae					
Common Cuckoo	*Cuculus canorus*	LC		X	passage migrant, and breeding summer visitor
Family: Strigidae					
Little Owl	*Athene noctua*	LC	X	X	resident breeder
Family: Caprimulgidae					
European Nightjar	*Caprimulgus europaeus*	LC		X	passage migrant, and breeding summer visitor
Family: Apodidae					
Common Swift	*Apus apus*	LC		X	passage migrant, and breeding summer visitor
Family: Coraciidae					
European Roller	*Coracias garrulous*	NT, CC		X	passage migrant, and breeding summer visitor
Family: Alcedinidae					
White-throated Kingfisher	*Halcyon smyrnensis*	LC	X	X	resident; winter visitor and passage migrant
Common Kingfisher	*Alcedo atthis*	LC		X	resident breeder
Pied Kingfisher	*Ceryle rudis*	LC	X	X	resident breeder
Family: Meropidae					
Blue-cheeked Bee-eater	*Merops [superciliosus] persicus*	LC		X	passage migrant, and breeding summer visitor
European Bee-eater	*Merops apiaster*	LC		X	passage migrant, and breeding summer visitor
Family: Upupidae					
Eurasian Hoopoe	*Upupa epops*	LC		X	breeding summer visitor; passage migrant

Bird Species Name	Scientific Name	Conservation Status	Winter Survey	Summer Survey	Migration Status
Family: Picidae					
Lesser Spotted Woodpecker	*Dendrocopos minor*	LC		X	resident breeder
Syrian Woodpecker	*Dendrocopos syriacus*	LC	X	X	resident breeder
Family: Laniidae					
Red-backed Shrike	*Lanius collurio*	LC		X	passage migrant, and summer breeding visitor
Daurian Isabelline Shrike	*Lanius isabellinus isabellinus*	LC		X	passage migrant
Lesser Grey Shrike	*Lanius minor*	LC		X	passage migrant, and breeding summer visitor
Woodchat Shrike	*Lanius senator*	LC		X	passage migrant, and breeding summer visitor
Masked Shrike	*Lanius nubicus*	CC		X	passage migrant, and breeding summer visitor
Family: Oriolidae					
Golden Oriol	*Oriolus oriolus*	LC		X	passage migrant, and breeding summer visitor
Family: Corvidae					
Eurasian Magpie	*Pica pica*	LC	X	X	resident breeder
Eurasian Jay	*Garrulus glandarius*	LC	X	X	resident breeder
Red-billed Chough	*Pyrrhocorax pyrrhocorax*	LC		X	resident breeder
Western Jackdaw	*Corvus monedula*	LC	X		resident; winter visitor
Rook	*Corvus frugilegus*	LC	X		winter visitor
Hooded Crow	*Corvus[corone] cornix*	LC	X	X	resident breeder
Northern Raven	*Corvus corax*	LC	X	X	resident breeder
Family: Paridae					
Sombre Tit	*Poecile lugubris*	CC		X	resident breeder
Great Tit	*Parus major*	LC	X	X	resident breeder
Blue Tit	*Cyanistes caeruleus*	LC	X	X	resident breeder
Family: Remizidae					
Eurasian Penduline Tit	*Remiz pendulinus*	LC	X	X	winter visitor and passage migrant
Family: Hirundinidae					
Sand Martin	*Riparia riparia*	LC		X	passage migrant, and breeding summer visitor
Barn Swallow	*Hirundo rustica*	LC	X	X	passage migrant, and breeding summer visitor

Bird Species Name	Scientific Name	Conservation Status	Winter Survey	Summer Survey	Migration Status
Red-rumped Swallow	*Cecropis daurica*	LC		X	breeding summer visitor; passage migrant.
House Martin	*Delichon urbicum [urbica]*	LC		X	passage migrant, and breeding summer visitor
Family: Aegithalidae					
Long-tailed Tit	*Aegithalos caudatus*	LC	X	X	resident breeder
Family: Alaudidae					
Calandra Lark	*Melanocorypha calandra*	LC	X		resident; winter visitor
Desert Lark	*Ammomanes deserti*	LC		X	resident breeder
Greater Short-toed Lark	*Calandrella brachydactyla*	LC	X		winter visitor; passage migrant and may breed
Crested Lark	*Galerida cristata*	LC	X	X	resident breeder
Eurasian Skylark	*Alauda arvensis*	LC	X	X	winter visitor
Family: Cisticolidae					
Graceful Prinia	*Prinia gracilis*	LC	X	X	resident breeder
Family: Pycnonotidae					
White-eared Bulbul	*Pycnonotus leucotis*	CC	X	X	resident breeder
Family: Sylviidae					
Cetti's Warbler	*Cettia cetti*	LC		X	resident breeder
Great Reed Warbler	*Acrocephalus arundinaceus*	LC		X	passage migrant, and breeding summer visitor
Clamorous Reed Warbler	*Acrocephalus stentoreus*	LC		X	status uncertain. probably resident
Sedge Warbler	*Acrocephalus schoenobaenus*	LC		X	passage migrant
Marsh Warbler	*Acrocephalus palustris*	LC		X	passage migrant; may breed
Eastern Olivaceous Warbler	*Iduna [Hippolais] pallida*	LC		X	passage migrant, and breeding summer visitor
Upcher's Warbler	*Hippolais languida*	LC		X	passage migrant, and breeding summer visitor
Willow Warbler	*Phylloscopus trochilus*	LC		X	passage migrant
Common Chiffchaff	*Phylloscopus collybita*	LC	X	X	passage migrant, and winter visitor
Eurasian Blackcap	*Sylvia atricapilla*	LC		X	passage migrant; may breed
Lesser Whitethroat	*Sylvia curruca*	LC		X	passage migrant and may breed
Common Whitethroat	*Sylvia communis*	LC		X	breeding summer visitor

Bird Species Name	Scientific Name	Conservation Status	Winter Survey	Summer Survey	Migration Status
Ménétries's Warbler	*Sylvia mystacea*	LC		X	breeding summer visitor; passage migrant.
Family: Timaliidae					
Iraq Babbler	*Turdoides altirostris*	CC	X	X	resident breeder
Family: Troglodytidae					
Winter Wren	*Troglodytes troglodytes*	LC	X		winter visitor
Family: Sittidae					
Eurasian Nuthatch	*Sitta europaea*	LC		X	resident breeder
Eastern Rock Nuthatch	*Sitta tephronota*	CC	X	X	resident breeder
Western Rock Nuthatch	*Sitta neumayer*	CC	X	X	resident breeder
Family:Tichodromadidae					
Wallcreeper	*Tichodroma muraria*	LC	X		winter visitor
Family: Sturnidae					
Rose-coloured Starling	*Sturnus roseus*	LC		X	passage migrant and may breed
Common Starling	*Sturnus vulgaris*	LC	X	X	winter visitor, passage migrant and some may breed
Family: Turdidae					
Eurasian Blackbird	*Turdus merula*	LC	X	X	resident breeder
European Robin	*Erithacus rubecula*	LC	X		winter visitor
White-throated Robin	*Irania gutturalis*	CC		X	breeding summer visitor; passage migrant
Thrush Nightingale	*Luscinia luscinia*	LC		X	passage migrant
Common Nightingale	*Luscinia megarhynchos*	LC		X	passage migrant, and breeding summer visitor
Rufous-tailed Scrub Robin	*Cercotrichas [Erythropygia] galactotes*	LC		X	breeding summer visitor
Black Redstart	*Phoenicurus ochruros*	LC	X		passage migrant and winter visitor
Common Redstart	*Phoenicurus phoenicurus*	LC		X	passage migrant, and breeding summer visitor
Whinchat	*Saxicola rubetra*	LC		X	passage migrant, and breeding summer visitor
Eurasian Stonechat	*Saxicola torquatus (S. rubicola)*	LC	X	X	Winter visitor; may breed
Isabelline Wheatear	*Oenanthe isabellina*	LC	X		Passage migrant, winter visitor, breeding summer visitor

Bird Species Name	Scientific Name	Conservation Status	Winter Survey	Summer Survey	Migration Status
Northern Wheatear	*Oenanthe oenanthe*	LC	X		passage migrant, and breeding summer visitor
Rufous-tailed Wheatear	*Oenanthe xanthoprymna*	CC	X	X	breeding summer visitor; passage migrant
Black-eared Wheatear	*Oenanthe hispanica*	LC		X	breeding summer visitor; passage migrant
Finsch's Wheatear	*Oenanthe finschii*	CC	X	X	resident breeder; winter visitor
Rufous-tailed Rock Thrush	*Monticola saxatilis*	LC		X	passage migrant, and breeding summer visitor
Blue Rock Thrush	*Monticola solitarius*	LC	X	X	resident; winter visitor and passage migrant
Family: Muscicapidae					
Spotted Flycatcher	*Muscicapa striata*	LC	X		passage migrant, and breeding summer visitor
Family: Cinclidae					
White-throated Dipper	*Cinclus cinclus*	LC		X	resident breeder
Family: Passeridae					
House Sparrow	*Passer domesticus*	LC	X	X	resident breeder
Spanish Sparrow	*Passer hispaniolensis*	LC	X	X	resident breeder
Dead Sea Sparrow	*Passer moabiticus*	CC		X	resident; breeding summer visitor
Eurasian Tree Sparrow	*Passer montanus*	LC		X	rare winter visitor; passage migrant
Pale Rockfinch	*Carpospiza brachydactyla*	CC		X	resident breeder
Rock Sparrow	*Petronia petronia*	LC		X	resident breeder
Yellow-throated Sparrow	*Gymnoris [Petronia] xanthocollis*	CC		X	passage migrant, and breeding summer visitor
Family: Motacillidae					
Western Yellow Wagtail	*Motacilla flava*	LC		X	passage migrant
Grey Wagtail	*Motacilla cinerea*	LC	X	X	resident breeder; winter visitor
White Wagtail	*Motacilla alba*	LC	X		resident; winter visitor
Tree Pipit	*Anthus trivialis*	LC		X	passage migrant; may breed
Water Pipit	*Anthus spinoletta*	LC	X	X	winter visitor; passage migrant

Bird Species Name	Scientific Name	Conservation Status	Winter Survey	Summer Survey	Migration Status
Meadow pipit	*Anthus pratensis*	LC	X		passage migrant, and winter visitor
Family: Fringillidae					
Common Chaffinch	*Fringilla coelebs*	LC	X	X	resident; winter visitor.
Red-fronted Serin	*Serinus pusillus*	LC		X	winter visitor, and some may breed
European Greenfinch	*Carduelis chloris*	LC	X	X	rare resident; winter visitor
European Goldfinch	*Carduelis carduelis*	LC	X	X	resident; winter visitor and passage migrant
Linnet	*Carduelis cannabina*	LC	X	X	resident; winter visitor
Family: Emberizidae					
Corn Bunting	*Emberiza [Miliaria] calandra*	LC	X	X	resident; winter visitor
Rock Bunting	*Emberiza cia*	LC	X		winter visitor; may be resident
Cinereous Bunting	*Emberiza cineracea*	NT, CC		X	breeding summer visitor; passage migrant
Black-headed Bunting	*Emberiza melanocephala*	LC		X	passage migrant, and breeding summer visitor
Common Reed Bunting	*Emberiza schoeniclus*	LC	X		winter visitor

proportion (over 50%) of the world population breeding in the Middle East; and those which have, or are believed to have, important wintering populations in Iraq.

Unlike Europe, bird population data is often lacking in the Middle East and especially so in Iraq where the first comprehensive surveys have only started in the last four years (and during the last two years in Kurdistan). This lack of data means that decisions, which species qualify as being of CC are rather subjective. However assignments will be refined as more surveys and population assessments are made. For now, it provides the best judgment of our bird conservation priorities (Porter et al in prep.).

The region's three large wetlands are the Dukan Reservoir (completed in 1959), the Mosul Reservoir (completed in 1983), and the Darbandikhan Reservoir (completed in 1961). Two of them (Dukan and Darbandikhan) along with an unfinished dam site at Bakhma, were defined by Evans (1994) as IBAs. Based on the KBA surveys, Darbandikhan (S1) and Dukan (S2) Lakes match the KBA criteria. These sites regularly support globally threatened species; birds congregating in important numbers, either when breeding, on passage, or in winter; and sites important for species that are threatened or declining throughout or in large parts of their range in the Middle East. For example: 2% of the Middle Eastern population of *Larus genei* was seen during its breeding season on these two lakes (Fig. 2). Mosul Lake (D10) also meets the criteria with 2% of the Middle Eastern population of *Phalacrocorax carbo* seen in winter at the lake and 18% of the Middle Eastern population of *Tadorna ferruginea* seen in winter and 1% of the Middle Eastern population of *Glareola pratincola* in summer. As with Dukan and Darbandikhan, this indicates that this lake regularly supports globally threatened species and birds congregating in important numbers, either when breeding, on passage, or in winter. Altun Kopri (E3) marshland in Erbil Govenorate is another important KBA site, because birds congregate at this wetland site in large numbers.

Table 2 lists the 11 top sites for globally threatened species and/or species which are threatened locally or declining throughout all or large parts of their range in the Middle East. It also lists species that are restricted wholly or largely to the Middle East.

The following sites also meet the KBA criteria: Gali Zanta and Garbeesh Mountain (D1) Ser Amadiya (D2), Atrush (D3), Benavi (D6), Zawita (D7), Mangesh (D8), Fishkhaboor (D11), Sararu (D13); in Erbil Governorate: Haji Omran (E1), Smaquli and Ashab Valley (E5), Taq Taq (E6), Bakhma (E7), Barzan (E8), Kherazook (E9), Bahraka (E11); and in Sulaimani Governorate: Kalar (S3), Ahmad Awa (S4A), Hawraman (S4B), Penjween (S5), Peramagroon (S6), Sargalu (S7), Chamchamal (S9), Chami Razan (S10), Qara Dagh (S11), and Sharbazher (S13). The remaining sites, which did not match KBA criteria for bird species as results of these surveys are: Kalakchi and Khazar (D12A and D12B), Duhok Lake (D9), Turaq Steppe (E4), Aski Kalak (E10), Sangaw (S14).

Destruction of habitats by gravel mining and tree cutting and other major threats to birds, such as uncontrolled hunting, were prevalent throughout the survey area, as

Figure 2. *Larus genei* at Dukan Lake (S2) in summer 2008 (photo by the author).

Table 2. Priority sites for bird conservation in Kurdistan, Iraq.

Site	Description
Darbandikahn Lake (S1)	Lake/Reservoir ecosystem on the Diyala Watershed southeast of Sulaimani - 25000 ha. This site supports the globally threatened Imperial Eagle *Aquila heliaca* – 8 counted in winter and Egyptian Vulture *Neophron percnopterus*. Other wintering birds include Smew *Mergellus albellus*, Common Goldeneye *Bucephala clanga*, Great Black-headed Gull *Larus ichthyaetus* and Wallcreeper *Tichodroma muraria.* White Storks *Ciconia ciconia* nest and there is a large breeding colony of Slender-billed Gulls *Larus genei* (760 birds counted).
Dukan Lake (S2)	Lake/Reservoir ecosystem on the Upper Little Zap Watershed northwest of Sulaimani - 7500 ha. This site holds small numbers of the globally threatened Lesser White-fronted Goose *Anser erythropus* and Imperial Eagle *Aquila heliaca* in winter when there are large flocks of Great Black-headed Gulls *Larus ichthyaetus* and large concentrations of larks. Breeding species include White Storks *Ciconia ciconia,* Egyptian Vultures, Slender-billed Gulls (4500), Gull-billed Terns *Gelochelidon nilotica* and passerines with a restricted range in the Middle East, such as Eastern Rock Nuthatch *Sitta tephronata.*.
Mosul Lake (D10)	Lake/Reservoir Ecosystem on the Tigris north of Mosel – 470 km². An important site holding in winter small numbers of Lesser White-fronted Goose *Anser erythropus* and over 9,000 Ruddy Shelduck *Tadorna ferruginea.* There are very important breeding colonies of Collared Pratincole *Glareola pratincola* (870 individuals), Slender-billed Gulls *Larus genei* (630), Gull-billed Tern *Gelochelidon nilotica* (760), Common Tern *Sterna hirundo* (350) and Little Tern *Sternula albifrons* (200)
Altun Kopri (E3)	Riparian marshland on the Little Zap River bordered by steppe ecosystem south of Erbil – 10 km². This site holds large numbers of waterfowl, notably Eurasian Coot *Fulica atra* with 11,500 counted. This varied habitat holds a large and diverse population of breeding/probable breeding birds including Little Grebe *Tachybaptus ruficollis,* Squacco Heron *Ardeola ralloides,* Purple Heron *Ardea purpurea,* Marsh Harrier *Circus aeruginosus,* Pin-tailed Sandgrouse *Pterocles alchata,* Pied Kingfisher *Ceryle rudis,* Penduline Tit *Remiz pendulinus,* Great Reed Warbler *Acrocephalus arundinaceus* and Dead Sea Sparrow *Passer moabiticus*
Barzan (E8)	This is a tribal protected area located to the northeast of Erbil City which represents mountains with woodlands of *Quercus* and the presence of some streams and rivers. The threatened Lesser Kestrel *Falco naumanni* and European Roller *Coracias garrulus* breed as well as Griffon Vulture *Gyps fulvus,* Booted Eagle *Aquila pennata,* Lesser Spotted Woodpecker *Dendrocopos minor* and several passerines restricted wholly or largely to the Middle East such as Eastern Rock Nuthatch *Sitta tephronota*.
Chami Razan (S10)	This site is located approximately 30 km to the northwest of Sulaimani City. It consists of a long valley with a stream that flows from the northeast down to the Little Zap and contains hills and rocky ridges with sparse oak woodlands. This site holds a good population of breeding birds of prey, notably Egyptian Vulture *Neophron percnopterus* and Griffon Vulture *Gyps fulvus*, Short-toed Eagle *Circaetus gallicus*, Bonelli's Eagle *Aquila fasciatus*, Long-legged Buzzard *Buteo rufinus* and probably Steppe Buzzard *Buteo buteo vulpinus*. European Roller *Coracias garrulus* may breed and there is a good breeding population of passerines, wholly or largely restricted to the Middle East, including Masked Shrike *Lanius nubicus*, Sombre Tit *Poecile lugubris*, Red-tailed Wheatear *Oenanthe xanthoprymna* and Eastern Rock Nuthatch *Sitta tephronota*.

Site	Description
Qara Dagh (S11)	This area located south of Sulaimani City and represents a mountainous area with many gorges, rocky slopes and valleys covered mainly by oak forest. There are farmlands and villages as well. This site holds breeding populations of the globally threatened Egyptian Vulture *Neophron percnopterus* and Lesser Kestrel *Falco naumani* as well as Griffon Vulture *Gyps fulvus*, Short-toed Eagle *Circaetus gallicus* and Long-legged Buzzard *Buteo rufinus*. Other breeding birds include European Roller *Coracias garrulus*, Masked Shrike *Lanius nubicus*, Woodchat Shrike *Lanius senator* (75 individuals counted) and Red-tailed Wheatear *Oenanthe xanthoprymna*.
Ser Amadia (D2)	This is a mountainous area with rocky cliffs, gorges, and a valley with streams; plant coverage is *Quercus*, *Juniperus*, *Puplus* with grasses. The globally threatened Lesser Kestrel *Falco naumani* and European Roller *Coracias garrulus* breed as well as Eurasian Nuthatch *Sitta europaea,* Western Rock Nuthatch *S. neumayer* Eastern Rock Nuthatch and Long-tailed Tit *Aegithalos caudatus.*
Haji Omran (E1)	This area is located on the Iran/Iraq border northeast of Erbil City and is surrounded by a number of mountains such as Sakran in the south, Halgurd in the west and Gardamn in the north, with hills, streams and meadows offering high plant diversity. It is considered one of the most important plant areas in Iraq. This site holds several breeding species restricted wholly or largely to the Middle East including Finsch's Wheatear *Oenanthe finschii*. Black-eared Wheatears *Oenanthe hispanic*a occur in good numbers
Sararu (D13)	Situated about 46 km northeast of Dohuk City and about 8 km^2 in size. It is a mountainous area with a valley including farmlands with walnuts and other trees. Breeding species include Lesser Kestrel *Falco naumani* and a diverse population of passerines including Masked Shrike *Lanius nubicus*, Eastern Rock Nuthatch *Sitta tephronota*, Sombre Tit *Poecile lugubris* and Long-tailed Tit *Aegithalos caudatus*. Levant Sparrowhawk *Accipiter brevipes* probably breeds.
Benavi (D6)	The site lies at 1,500-1,700 m and includes a valley containing Benavi village and the adjacent mountain ridge. The slopes are rocky and grassy, with a rich herb flora and isolated *Quercus* shrubs and trees. Benavi holds a good population of several species that are restricted wholly or largely to the Middle East, including Finsch's Wheatear *Oenanthe finschii* and Sombre Tit *Poecile lugubris*.

is the case for Iraq as a whole. These sites should be monitored for and protected from these threats.

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References

Ararat K, Abid IM, Abdulrahman S (2008) Key Biodiversity Survey of Kurdistan, Norhtern Iraq: Site Review for Birds, Botany and Fisheries, Winter & Summer 2008. Sulaimani, Iraq: Nature Iraq. 119p.

Eken G, Evans E, Karataş A, Özge Balkiz O, Karaçetin E, Kiliç T, Özbağdatli N, Neumann-Denzau G, Gem E, Karataş A (2004) Hotspots Revisited: Irano-Anatolian. Retrieved from http://www.biodiversityscience.org/publications/hotspots/IranoAnatolian.html on 10 October 2008.

Evans MI (1994) Important Bird Areas in the Middle East, BirdLife Conservation Series No. 2. Cambridge, UK: BirdLife International.

IUCN (2001) IUCN Red List Categories and Criteria: Version 3.1. IUCN Species Survival Commission. Gland, Switzerland and Cambridge, UK: IUCN. ii + 30 pp.

Mullarney K, Svensson L, Zetterström D, Grant PJ (2001) Collins Field Guide to the Birds of Britain & Europe. 2nd Edition. London, UK: Collins.

Porter RF, Aspinall S. In prep. Birds of the Middle East (second edition). London, UK: Helm/ A&C Black,

Porter RF, Christensen S, Schiermacker-Hansen P (1996) Field Guide to the Birds of the Middle East. Helm Field Guides. London, UK: A&C Black Publishers Ltd**.**

Porter RF, Salim M, Ararat K. In prep. The Species of Conservation Concern in Iraq Nature Iraq/BirdLife International.

Salim M, Porter RF, Christensen S, Schiermacker-Hansen P, Jbour S (2006) Birds of Iraq. Amman Jordan: Nature Iraq and BirdLife International. (In Arabic).

Delany S, Scott D (2006) Waterbird Populations Estimates. 4th Edition. Netherlands: Wetlands International.

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RESEARCH ARTICLE

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A summary of birds recorded in the marshes of southern Iraq, 2005–2008

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Abstract

The marshlands of Lower Mesopotamia witnessed severe draining programs during late 1980s and early 2000s, which turned vast areas of the former water body into desert areas. New field surveys of birds and their habitats in the marshes of southern Iraq were launched in 2005 through a national and international partnership of non-government organizations, ministries and donor agencies. This has resulted in the collection and collation of new data on the status, distribution and habitat requirements of birds and other biota in Key Biodiversity Areas (KBAs) in Iraq from 2005 to 2008. This paper summarizes the bird data obtained in these surveys in the southern marshes, during which 159 species of birds were recorded; of these 34 are considered to be of conservation concern, including eight that are globally threatened.

Keywords

KBA, Iraq, birds

Introduction: The focus on birds

Birds have become an important component of the Iraq Key Biodiversity Areas (KBA) Project that has been conducted by Nature Iraq (NI) since 2004. This is being done in cooperation with the Iraq Ministry of Environment (MoE), Birdlife International and Iraqi universities with international financial support by several donors including the Canadian International Development Agency (2004–2006) and the Italian Ministry of Environment, Land and Sea (2006–2008). An overview of the KBA Project is presented in Rubec and Bachmann (2009). This has been helped by the availability of historical data for critical biodiversity areas in Iraq, thus enabling comparison with current observations, facilitating the analyses of ecosystem changes and assessing the ecological status of each site. Comprehensive waterbird counts made over the last 40 years throughout Europe and Asia – notably by Wetlands International and BirdLife International – are facilitating such regional comparisons.

Other wildlife groups and ecological data have a less well developed history of record in Iraq and fewer international networks on which to draw survey expertise. Thus, birds are being used as the major indicator of the health of Iraq's biological resources, particularly as they are also an important component of global efforts to conserve and ensure wise use of wetlands and other biologically important habitats. Comprehensive field observations and interviews since 2004 with local residents have enabled development of a good indication of the biological health of Iraq's key sites for biodiversity.

As a part of the KBA Project, bird surveys were conducted at selected wetland areas in southern Iraq during each of the summers and winters from 2005 to 2008. As noted in Fig. 1, seven major wetland areas were surveyed in three governorates (Basrah, Missan and Thi-Qar) in southern Iraq. KBA surveys of the three governorates of Kurdistan (Erbil, Sulaimani and Dohuk) in the northern area of Iraq were added to the overall project in 2007 (Nature Iraq 2007). These are also shown for information on Fig. 1, but results of that work are otherwise not included in this paper. Initial selection of potential KBA sites drew upon Important Bird Areas described by Evans (1994) and potential Ramsar Wetlands of International Importance described by Scott (1995). At most of these southern Iraq KBA complexes, especially the larger ones, multiple sampling sites (refereed in the species section below as "monitoring" sites) were required to obtain a proper picture of bird populations and distribution. These KBA survey sites are often found within very extensive wetlands (as described in Rubec and Bachmann 2009). The individual area of southern KBA sites ranges from 50 to 350,000 hectares, making selection of sampling sites difficult. Reports on the field surveys for the southern and northern KBA projects have been prepared by Nature Iraq (Abdulhasan and Salim 2008; Ararat et al. 2008). In the south, the teams must also seriously consider security issues and this has had a bearing on the selection of sites for survey.

About 70% of the bird surveys were conducted using motorized boats, otherwise travel was by car or on foot. The main fieldwork and surveys in the Hammar and Sinaf Marshes were done by vehicle, to reduce travel time required between sites. Due to the occurrence of dense vegetation in the Central and the Hawizeh Marshes, the main means of transportation was motorized canoes. Local residents were extremely helpful in assisting with information on the presence or absence of certain species.

Observations were made using 30 X telescopes and 8 X binoculars, with recording back-up by photography. Indeed, Nature Iraq has a comprehensive library of bird photographs and videos taken during the surveys. All bird data was checked and vetted by Richard Porter of BirdLife International before being entered into Nature Iraq's database.

Sites and survey locations were plotted by GPS or Thuraya satellite phone with the aid of 1:100,000 and 1:250,000 scale maps. *Collins Bird Guide* (Mullarney et al. 1999) and the *Field Guide to the Birds of the Middle East* (Porter et al. 1996) were initially the main references used. Later, the new book *Birds of Iraq* (Salim et al. 2006), was also used. Designation of the status of specific species follows standardized international protocols developed by BirdLife International (2000).

Summary of bird observations

The following information summarizes some of the more important observations made during the 2005 to 2008 surveys. It is not intended to be a comprehensive account but to highlight those records of conservation significance. Some comparisons with the counts made in the late 1970s have been attempted. Population counts have not been included but constitute a growing database being managed by BirdLife International and Nature Iraq. They are the subject of ongoing analyses and are included in detailed

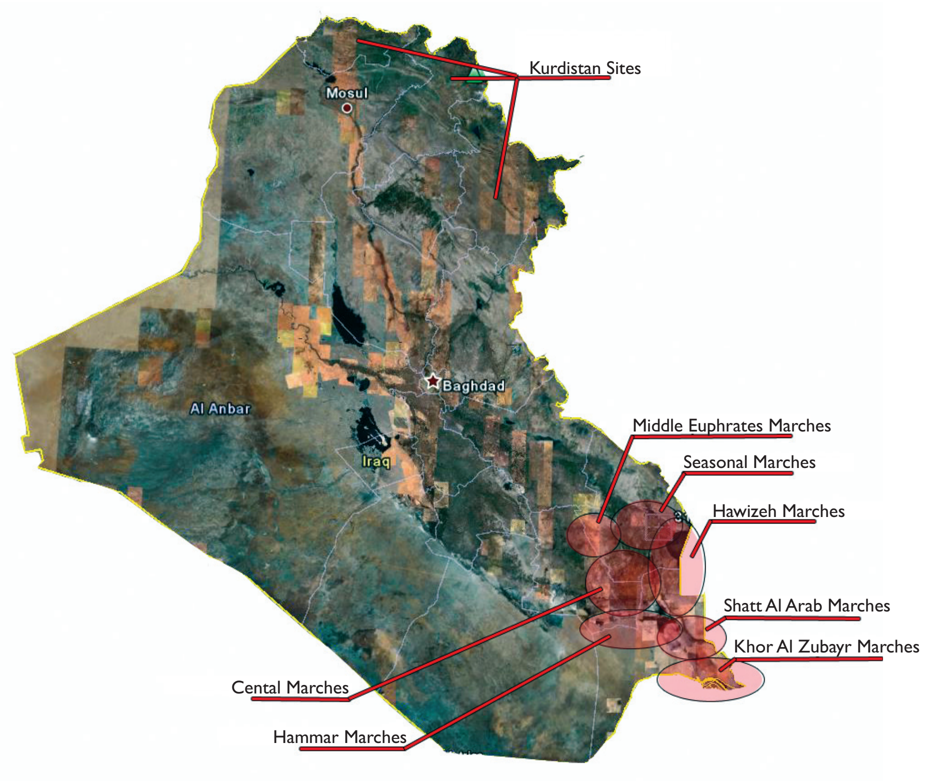

Figure 1. The seven major wetland survey areas of southern Iraq and the locations of survey sites in Kurdistan, northern Iraq.

project reports (e.g. Abdulhassan and Salim 2008, Ararat et al. 2008) and in BirdLife International's global database. A full report on all the bird data collected is in preparation.

The list of birds recorded during the summer and winter surveys from 2005 to 2008 are presented in Table 1. This shows that 159 species were recorded, of which 53 were breeding with a further 10 probably or possibly breeding. A total of 44 species are considered to be resident. In addition, 110 species were observed as winter visitors from their European and Asian breeding areas. As would be expected, the majority of species observed in the southern marshes are wetland dependant – 107 in total.

Of great significance is the fact that eight species recorded in the southern surveys are "globally threatened (GT)" and a further 26 species are judged to be of "conservation concern (CC)". Particular attention to these two groups of birds was paid during the surveys. These groups of birds are defined by BirdLife International as:

Globally threatened (GT): Red Data species identified by BirdLife International because of their global endangered, vulnerable or near-threatened status.

Conservation concern (CC): This category includes globally threatened species; Iraq endemic species; species known to be declining in all or most of their range; species for which Iraq has a significant Middle East breeding population; and species for which Iraq is known to have a globally important wintering population. These criteria are still being assessed and developed by Richard Porter of BirdLife International.

Globally threatened birds in the southern marshes of Iraq

Of the 34 species of conservation concern recorded during the 2005 to 2008 KBA surveys, eight are globally threatened. Brief notes on their occurrence are given below. They are either resident breeders, winter visitors, or passage migrants.

Marbled Duck (*Marmaronetta angustirostris*): This globally vulnerable species was observed in both summer and winter at over 30 monitoring sites. Breeding was proven and the largest flock recorded was 1300 in winter 2008. Salim (2004a, b, c) has previously recorded Marbled Duck in recent years and it is likely that the southern marshes are a major global stronghold for both breeding and wintering birds of this species. In winter 2007, a number were found being sold live in the local markets and this has prompted a poster-backed public awareness campaign that will attempt to help control indiscriminate and illegal hunting.

Ferruginous Duck (*Aythya nyroca*): This globally near-threatened species was recorded at 12 monitoring sites in winter and seen in all winters, with the largest flock being 74 in winter 2006; several smaller flocks (for example of 16, 47 and 60) were also observed. Scott and Carp (1982) did not record this species in their southern marshes survey of 1979, but the highest number counted historically is 31 individuals by George and Vielliard (1970). It is likely that further surveys will show this duck to be more common and more widespread in the Mesopotamian marshes, as it has been recorded in flocks of up to 344 in winter in neighboring Syria (Porter and Scott 2005).

Table 1. Birds recorded during KBA surveys of the southern marshes of Iraq in winter and summer 2005 to 2008 (GT = globally threatened, CC = conservation concern)

Common name (English)	Scientific name	Summer	Winter	Status as determined by these surveys
Black Francolin	*Francolinus francolinus*	+	+	Resident breeder
Common Quail	*Coturnix coturnix*	+	+	Passage migrant and winter visitor
Greylag Goose	*Anser anser*	-	+	Winter visitor
Whooper Swan	*Cygnus cygnus*	-	+	Rare winter vistor
Greater White-fronted Goose	*Anser albifrons*	-	+	Winter visitor
Common Shelduck	*Tadorna tadorna*	-	+	Winter visitor
Ruddy Shelduck	*Tadorna ferruginea*	-	+	Winter visitor
Gadwall	*Anas strepera*	-	+	Winter visitor
Eurasian Wigeon	*Anas penelope*	-	+	Winter visitor
Mallard	*Anas platyrhynchos*	+	+	Winter visitor; some remain in summer
Northern Shoveler	*Anas clypeata*	+	+	Winter visitor; some present in summer
Northern Pintail	*Anas acuta*	-	+	Winter visitor
Garganey	*Anas querquedula*	+	+	Winter visitor; may also breed
Eurasian Teal	*Anas crecca*	-	+	Winter visitor
Marbled Duck **CC, GT**	*Marmaronetta angustirostris*	+	+	Resident breeder and winter visitor
Red-crested Pochard **CC**	*Netta rufina*	-	+	Winter visitor
Common Pochard	*Aythya ferina*	-	+	Winter visitor
Ferruginous Duck **CC, GT**	*Aythya nyroca*	+	+	Winter visitor; some may remain to breed
Tufted Duck	*Aythya fuligula*	-	+	Winter visitor
White-headed Duck **CC, GT**	*Oxyura leucocephala*	-	+	Winter visitor
Little Grebe (Dabchick)	*Tachybaptus ruficollis*	+	+	Resident breeder and winter visitor
Great Crested Grebe	*Podiceps cristatus*	+	+	Resident breeder and winter visitor
Black-necked Grebe	*Podiceps nigricollis*	-	+	Winter visitor
Greater Flamingo **CC**	*Phoenicopterus [ruber] roseus*	+	-	Passage migrant and winter visitor
Western White Stork	*Ciconia ciconia*	+	+	Winter visitor; some may breed
Sacred Ibis **CC**	*Threskiornis aethiopicus*	+	+	Resident breeder
Glossy Ibis	*Plegadis falcinellus*	+	+	Winter visitor; may also breed
Eurasian Spoonbill **CC**	*Platalea leucorodia*	+	+	Breeding summer visitor
Eurasian Bittern **CC**	*Botaurus stellaris*	+	+	Resident breeder and winter visitor
Little Bittern	*Ixobrychus minutus*	+	+	Resident breeder and winter visitor

Common name (English)	Scientific name	Summer	Winter	Status as determined by these surveys
Black-crowned Night Heron	*Nycticorax nycticorax*	+	+	Resident breeder and winter visitor
Squacco Heron	*Ardeola ralloides*	+	+	Resident breeder and winter visitor
Cattle Egret	*Bubulcus ibis*	+	+	Resident breeder and winter visitor
Grey Heron	*Ardea cinerea*	+	+	Resident breeder and winter visitor
Goliath Heron **CC**	*Ardea goliath*	+	+	Reported to breed
Purple Heron	*Ardea purpurea*	+	+	Resident breeder and winter visitor
Great Egret	*Ardea [Egretta] alba*	-	+	Winter visitor
Little Egret	*Egretta garzetta*	+	+	Winter visitor; some remain in summer
Western Reef Heron (Reef Egret)	*Egretta gularis*	+	-	Present in summer
Great White Pelican **CC**	*Pelecanus onocrotalus*	-	+	Winter visitor
Pygmy Cormorant **CC**	*Phalacrocorax pygmaeus*	+	+	Resident breeder and winter visitor
Great Cormorant	*Phalacrocorax carbo*	-	+	Winter visitor
Darter (African Darter) **CC**	*Anhinga [rufa] melanogaster*	+	+	Resident breeder
Common Kestrel	*Falco tinnunculus*	-	+	Winter visitor
Western Marsh Harrier	*Circus aeruginosus*	-	+	Winter visitor
Black-winged Kite	*Elanus caeruleus*	+	+	Rare resident
Long-legged Buzzard	*Buteo rufinus*	-	+	Winter visitor
Hen Harrier	*Circus cyaneus*	-	+	Winter visitor
Eurasian Sparrowhawk	*Accipiter nisus*	-	+	Winter visitor
Greater Spotted Eagle **CC, GT**	*Aquila clanga*	-	+	Winter visitor
Steppe Eagle **CC**	*Aquila nipalensis*	-	+	Winter visitor
Asian Imperial Eagle **CC, GT**	*Aquila heliaca*	-	-	
Macqueen's Bustard **GT, CC**	*Chlamydotis macqueenii*		+	Winter visitor
Water Rail	*Rallus aquaticus*	-	+	Winter visitor
Little Crake	*Porzana parva*	-	+	Winter visitor
Spotted Crake	*Porzana porzana*	-	+	Winter visitor
Purple Swamphen **CC**	*Porphyrio porphyrio*	+	+	Resident breeder
Common Moorhen	*Gallinulua chloropus*	+	+	Resident breeder and winter visitor
Eurasian Coot	*Fulica atra*	+	+	Resident breeder and winter visitor
Crab-plover **CC**	*Dromas ardeola*	+	-	Possibly resident, but only recorded in summer
Black-winged Stilt	*Himantopus himantopus*	+	+	Resident breeder and winter visitor

Common name (English)	Scientific name	Summer	Winter	Status as determined by these surveys
Pied Avocet (Avocet)	*Recurvirostra avosetta*	+	+	Resident breeder and winter visitor
Northern Lapwing	*Vanellus vanellus*	-	+	Winter visitor
Spur-winged Lapwing **CC**	*Vanellus spinosus*	+	+	Resident breeder and winter visitor
Red-wattled Lapwing	*Vanellus indicus*	+	+	Resident breeder and winter visitor
White-tailed Lapwing **CC**	*Vanellus leucurus*	+	+	Resident breeder and winter visitor
Common Ringed Plover	*Charadrius hiaticula*	-	+	Winter visitor
Little Ringed Plover	*Charadrius dubius*	+	+	Winter visitor; some may breed
Kentish Plover	*Charadrius alexandrinus*	+	+	Resident breeder and winter visitor
Common Snipe	*Gallinago gallinago*	-	+	Winter visitor
Black-tailed Godwit **CC, GT**	*Limosa limosa*	-	+	Winter visitor
Bar-tailed Godwit	*Limosa lapponica*	-	+	Winter visitor
Whimbrel	*Numenius phaeopus*	+	+	Winter visitor; some remain in summer
Eurasian Curlew **CC**	*Numenius arquata*	+	+	Winter visitor; some remain in summer
Spotted Redshank	*Tringa erythropus*	-	+	Winter visitor
Common Redshank	*Tringa totanus*	+	+	Winter visitor; some remain in summer
Marsh Sandpiper	*Tringa stagnatilis*	-	+	Winter visitor
Common Greenshank	*Tringa nebularia*	+	+	Winter visitor; some remain in summer
Green Sandpiper	*Tringa ochropus*	-	+	Winter visitor
Wood Sandpiper	*Tringa glareola*	-	+	Winter visitor
Common Sandpiper	*Actitis hypoleucos*	+	+	Winter visitor; some remain in summer
Ruddy Turnstone	*Arenaria interpres*	+	-	Recorded in summer, but these are wintering birds that have not returned
Little Stint	*Calidris minuta*	+	+	Winter visitor; some remain in summer
Temminck's Stint	*Calidris temminckii*	-	+	Winter visitor
Curlew Sandpiper	*Calidris ferruginea*	+	+	Winter visitor; some remain in summer
Dunlin	*Calidris alpina*	-	+	Winter visitor
Ruff	*Philomachus pugnax*	-	+	Winter visitor
Collared Pratincole **CC**	*Glareola pratincola*	+	-	Breeding summer visitor
Yellow-legged Gull	*Larus michahellis*	?	?	Status uncertain
Armenian Gull **CC**	*Larus armenicus*	+	+	Winter visitor; some remain in summer
Lesser Black-backed Gull	*Larus fuscus graellsii/ intermedius/ fuscus*	-	+	Winter visitor

Common name (English)	Scientific name	Summer	Winter	Status as determined by these surveys
White-headed Gull sp.	*Larus sp*		+	
Great Black-headed Gull (Pallas's Gull)	*Larus ichthyaetus*	-	+	Winter visitor
Common Black-headed Gull	*Larus ridibundus*	+	+	Winter visitor; some remain in summer
Slender-billed Gull **CC**	*Larus genei*	+	+	Resident breeder and winter visitor
Little Gull	*Larus minutus*	-	+	Winter visitor
Gull-billed Tern	*Gelochelidon [Sterna] nilotica*	+	+	Winter visitor and breeding resident
Caspian Tern **CC**	*Hydroprogne [Sterna] caspia*	+	+	Winter visitor; also recorded in summer
Common Tern	*Sterna hirundo*	+	-	Breeding summer visitor
White-cheeked Tern	*Sterna repressa*	+	-	Status uncertain
Little Tern	*Sternula [Sterna] albifrons*	+	-	Breeding summer visitor
Whiskered Tern	*Chlidonias hybrida*	+	+	Breeding resident and winter visitor
Black Tern	*Chlidonias niger*	+	-	Vagrant
Pin-tailed Sandgrouse **CC**	*Pterocles alchata*	+	-	Breeding resident
Spotted Sandgrouse **CC**	*Pterocles senegallus*	+	-	Breeding resident
Rock Dove	*Columba livia*	+	-	Probably a breeding resident
Stock Dove	*Columba oenas*	-	+	Winter visitor
Common Woodpigeon	*Columba palumbus*	-	+	Winter visitor
Eurasian Collared Dove	*Streptopelia decaocto*	-	+	Probably a breeding resident
Laughing Dove	*Streptopelia senegalensis*	-	+	Probably a breeding resident
Egyptian Nightjar	*Caprimulgus aegyptius*	+	-	Breeding summer visitor
Indian Roller	*Coracias benghalensis*	+	-	Breeding summer visitor
White-throated Kingfisher	*Halcyon smyrnensis*	+	+	Breeding resident
Common Kingfisher	*Alcedo atthis*	+	+	Winter visitor; also recorded in summer
Pied Kingfisher	*Ceryle rudis*	+	+	Breeding resident
Blue-cheeked Bee-eater	*Merops [superciliosus] persicus*	+	-	Breeding summer visitor
Eurasian Hoopoe	*Upupa epops*	+	-	Status uncertain
Daurian/Turkestan Shrike	*Lanius isabellinus*	-	+	Winter visitor
Great Grey Shrike/ Southern Grey Shrike	*Lanius excubitor/ meridionalis*	-	+	Winter visitor
Eurasian Magpie	*Pica pica*	-	+	Winter visitor
Rook	*Corvus frugilegus*		+	Winter visitor
Hooded Crow **CC, Endemic Race**	*Corvus [corone] cornix*	+	+	Probably a breeding resident

Common name (English)	Scientific name	Summer	Winter	Status as determined by these surveys
Grey Hypocolius **CC, Endemic**	*Hypocolius ampelinus*	+	+	Breeding resident and winter visitor
Sand Martin	*Riparia riparia*	+	-	Breeding summer visitor
Barn Swallow	*Hirundo rustica*	+	-	Probably a breeding summer visitor
Greater Hoopoe-Lark	*Alaemon alaudipes*	+	-	Probably a breeding resident; not yet recorded in winter
Desert Lark	*Ammomanes deserti*	-	+	Probably a breeding resident; not yet recorded in summer
Crested Lark	*Galerida cristata*	+	+	Breeding resident
Eurasian Skylark	*Alauda arvensis*	+	-	Status uncertain; probably a winter visitor that occasional- ly remains in summer
Zitting Cisticola	*Cisticola juncidis*	-	+	Probably a breeding resident; not yet observed in summer
Graceful Prinia	*Prinia gracilis*	+	+	Breeding resident
White-cheeked Bulbul **CC**	*Pycnonotus leucogenys*	+	+	Breeding resident
Cetti's Warbler	*Cettia cetti*	-	+	Winter visitor
Basra Reed Warbler **CC, GT, Endemic**	*Acrocephalus griseldis*	+	-	Breeding summer visitor
Great Reed Warbler	*Acrocephalus arundinaceus*	+	-	Breeding summer visitor
Clamorous Reed Warbler	*Acrocephalus stentoreus*	+	-	Breeding summer visitor
Eurasian Reed Warbler	*Acrocephalus scirpaceus*	+	-	Breeding summer visitor
Chiffchaff	*Phylloscopus collybita*	-	+	Winter visitor
Iraq Babbler **CC, Endemic**	*Turdoides altirostris*	+	+	Breeding resident
Common Babbler	*Turdoides caudata*	+	+	Breeding resident
Common Starling	*Sturnus vulgaris*	-	+	Winter visitor
Common Blackbird	*Turdus merulus*	-	+	Winter visitor
European Robin	*Erithacus rubecula*	-	+	Winter visitor
Bluethroat	*Luscinia svecica*	-	+	Winter visitor
Rufous-tailed Scrub Robin	*Cercotrichas galactotes*	+	-	Breeding summer visitor
Black Redstart	*Phoenicurus ochruros*	-	+	Winter visitor
Eurasian Stonechat	*Saxicola torquatus (S. rubicola)*	-	+	Winter visitor
Isabelline Wheatear	*Oenanthe isabellina*	+	+	Winter visitor: some may remain to breed
Desert Wheatear	*Oenanthe deserti*	-	+	Winter visitor
House Sparrow	*Passer domesticus*	+	+	Breeding resident
Spanish Sparrow	*Passer hispaniolensis*	-	+	Winter visitor
Dead Sea Sparrow **CC**	*Passer moabiticus*	+	+	Breeding resident

Common name (English)	Scientific name	Summer	Winter	Status as determined by these surveys
Chestnut-shouldered Petronia	*Gymnoris [Petronia] xanthocollis*	+	-	Breeding summer visitor
Western Yellow Wagtail	*Motacilla flava*	+	-	Status uncertain; summer visitor that may breed
White Wagtail	*Motacilla alba*	-	+	Winter visitor
Tawny Pipit	*Anthus campestris*	-	+	Winter visitor
Water Pipit	*Anthus spinoletta*	+	+	Winter visitor; some remain in summer.
Reed Bunting	*Emberiza aureala*		+	Winter visitor
Corn Bunting	*Emberiza [Miliaria] calandra*	-	+	Winter visitor

White-headed Duck (*Oxyura leucocephala*): The 2005 winter survey identified 19 White-headed Duck at Umm an-Ni'aaj Marsh during February and March. They were found in waters of 2.0–2.8 m depth, together with large groups of other diving ducks. Previously unrecorded in the southern marshes of Iraq, this observation clearly indicates the importance of the area, at least in winter, for a species identified by BirdLife International as globally endangered.

Basra Reed Warbler (*Acrocephalus griseldis*): Because of the difficulties of access and surveys, the Basra Reed Warbler had not been recorded in Iraq in recent years although it had continued to be trapped at banding stations on its African migration route. It was thus exciting to have confirmed sightings in the marshes of Iraq during all summers from 2005 to 2008. This Iraqi breeding endemic has been designated as globally endangered by BirdLife International, as a result of the destruction of its *Phragmites* habitat through drainage in the last 25 years. The Basra Reed Warbler was recorded at 25 monitoring sites at three KBAs with up to 37 individuals recorded on transects at one site in the Hawizeh Marsh. There was an apparent increase in the number of Basra Reed Warbler trapped on migration in East Africa in 2005, possibly indicating a correlation with the restoration of the marshes of Iraq. This species is now the subject of an intensive scientific and photographic study by Nature Iraq.

Black-tailed Godwit (*Limosa limosa*): This wetland dependant species was recently assigned near-threatened status by BirdLife International. It was recorded in winter at 20 monitoring sites in southern Iraq in all years from 2005 to 2008, with the highest count being 2010 individuals in the winter of 2008.

Asian Imperial Eagle (*Aquila heliaca*): This large eagle was recorded in winter at six sites in the southern marshes with a highest count of eight birds in a loose association. It is a globally near-threatened species.

Greater Spotted Eagle (*Aquila clanga*): Recorded at eight sites, with a highest count of eight individuals, it has been observed during three of the four winters from 2005 to 2008. It is another wetland-dependant, globally near-threatened species.

Macqueen's Bustard (*Chlamydotis macqueenii*): This is another globally near-threatened species that was recorded in the winter of 2008 in areas near to the Hawizeh

Marsh. These observations came to light as a result of hunters displaying shot birds. The status of this species in Iraq requires detailed study.

Other birds of conservation concern in the southern marshes of Iraq

The southern KBA marshland sites harbour good populations of three Mesopotamian endemic/near endemic birds, namely the Basra Reed Warbler (*Acrocephalus griseldis*), Iraq Babbler (*Turdoides altirostris*) and the Grey Hypocolius (*Hypocolius ampelinus)*. The status of the Basra Reed Warbler has already been mentioned, the other two are discussed below. These endemic/near-endemic species constitute three of the 34 birds of conservation concern recorded during the KBA surveys in the southern marshes. In addition to globally threatened species (described above), the status of seven other species of conservation concern is outlined below.

Sacred Ibis (*Threskiornis aethiopicus*): The southern marshes of Iraq are one of only two known breeding sites in the Middle East for this ibis. It was recorded in all years, both summer and winter from 2005 to 2008, in three monitoring sites. A total of 26 adults were observed at the Umm an-Ni'aaj Marsh breeding colony in Hawizeh Marsh in the summer of 2005. This site is a multi-species colony with Pygmy Cormorants, several heron species and African Darters.

Eurasian Bittern (*Botaurus stellaris*): Eurasian Bitterns have been seen or heard booming at a total of 11 monitoring sites throughout the southern marshes. Locals interviewed believed that its distinctive booming call came from a strange "monster" living inside the dense reed beds, heard only in the past year. In the summer of 2006, a total of 52 Eurasian Bittern were seen or heard throughout the marshes, with a highest count of eight birds. Previous winter surveys in 1968 to 1979 only recorded one Eurasian Bittern (Scott and Carp 1982). The southern marshes of Iraq would appear to be an important breeding and wintering area for this species. The Eurasian Bittern is otherwise believed to be declining throughout much of its range.

Goliath Heron (*Ardea goliath*): Although the largest of the heron species, the Goliath Heron remains quite elusive in Iraq. However, reports from local tribesman had indicated that it was still present in small numbers and was probably breeding. Recent observations with photographic documentation have confirmed the presence of this species in the Hawizeh Marsh during the summer and winter months of 2008 (Hussain personal communication).

Pygmy Cormorant (*Phalacrocorax pygmaeus*): Recorded at 25 monitoring sites, the Pygmy Cormorant was observed to be most common in the eastern areas of Hawizeh Marsh in both summer and winter of all years from 2005 to 2008, with a few scattered individuals in the central marsh. The highest counts were in the summer of 2006 when the birds at the 'Umm an-Ni'aaj breeding colony numbered over 1500. In the winter of 2006, a total of 1621 were recorded, suggesting that it is resident, though it is likely that these birds also arrive from European breeding grounds to spend the winter in the southern Iraqi marshes. This species was previously designated as a globally threatened species by BirdLife

International, but now, with increasing numbers observed in Eurasia, it is no longer assigned to this category. Historical records indicate the Pygmy Cormorant occurred in very large numbers in the southern Iraq marshes (Allouse 1953, 1962) but observations from 1968 to 1979 (Scott and Carp 1982) appear to be similar to those of the present survey.

African Darter (*Anhinga rufa*): This darter was recorded at five monitoring sites in two KBAs (the Hammar and Hawizeh Marshes) in all years and seasons from 2005 to 2008. The highest count was 21 at Umm an-Ni'aaj and Al-'Udhaim in Hawizeh Marsh during the February to March and summer surveys of 2005. This species nests in these locations and young were observed, showing that the species still breeds in Iraq. Locals indicated that the African Darter is common in the area, but that its numbers decrease in the winter. They further noted that its eggs and chicks used to be a source of food and that it breeds in colonies with herons, Sacred Ibis and European Spoonbill. It seems likely that the African Darter never disappeared as a breeding bird from the marshes of southern Iraq where it was formerly recorded by Allouse (1962). This is the only known area in the Middle East where the African Darter breeds.

Grey Hypocolius (*Hypocolius ampelinus*): This near-endemic species was observed in several sites throughout the southern marshes and their environs in all years, with counts of over 20 birds. In 2006 the summer survey occurred over a month later (in late July and early August) and this may account for only three being seen. By late summer breeding birds and their young would have dispersed. In the winter of 2006, six birds were seen at the Hammar Marsh. It is evident that southern Iraq is a very important breeding and wintering area for this Middle Eastern species.

Iraq Babbler (*Turdoides altirostris*): This Mesopotamian endemic has recently extended its range to Syria and Turkey, indicating that an expansion northwards has occurred, particularly along the Euphrates River. During all the marshland surveys, it was frequently encountered in small numbers in *Phragmites* reed beds in most sites visited, suggesting a healthy population.

Finally, it is worthy of mention that several species of waterbirds observed during the winter surveys were in good numbers, especially waterfowl, herons, their allies and waders with Gadwall (*Anas strepera*), Northern Shoveler (*Anas clypeata*), Northern Pintail (*Anas acuta*) and Eurasian Teal (*Anas crecca*) being the most common ducks. Of particular note among other waterbirds were the large flocks of Great White Pelicans (*Pelecanus onocrotalus*) up to 1800 and Eurasian Spoonbill (*Platalea leucorodia*) – up to 512. The most common wader was the Ruff (*Philomachus pugnax*), with one flock totaling 3120 individuals.

Other linked conservation developments

A comprehensive bird field guide: In November 2006, Nature Iraq and BirdLife International published a field guide, "The Birds of Iraq" (Salim et al. 2006). This book was derived from the text and colour plates of the Arabic and English language versions of the publication "Birds of the Middle East" (Porter et al. 1996, 2006). Covering the

387 species recorded in Iraq, this is the first comprehensive bird guide for an Arabic-speaking country. With the support of several international agencies, "Birds of Iraq" has been distributed to biologists, conservationists and students in Iraq and is now the definitive bird identification tool for those undertaking the KBA surveys.

A children's book: Also in 2006 Nature Iraq published a children's book on birds, supported and encouraged by the Ministry of Environment. It has been distributed to schools throughout the southern governorates of Iraq.

Sustainable Hunting Education Program: Considerable hunting pressure on globally threatened species (notably Macqueen's Bustard and Marbled Duck) was witnessed during the KBA surveys. As a result, Nature Iraq has started a poster-backed campaign to educate those hunters in the southern marshes in an attempt to reduce indiscriminate hunting of endangered species.

Conclusions

The most encouraging finding of the 2005 to 2008 KBA bird surveys is that no bird species has become extirpated in the southern marshes of Iraq despite the drainage and water flow reductions of the previous 25 years. Out of 159 bird species noted in these surveys, some 34 species are of "conservation concern" including eight species that are "globally threatened". Indeed, many species appear to still have healthy breeding and wintering populations. What may be Iraq's most important species, the globally endangered Basra Reed Warbler, was found in good numbers in several areas. It was also exciting to discover that the African Darter, Sacred Ibis and Goliath Heron still breed here.

Moreover, key results of this work include the: (a) establishment of a good foundation for national biodiversity programs; (b) creation of a significant baseline for a national biodiversity assessment; (c) assisting the capacity of the Government of Iraq to make sound decisions on future environmental management areas, creation of protected areas and the nomination of additional Wetlands of International Importance under the Ramsar Convention (as now successfully done for Hawizeh Marsh); and (d) initiation of science and public awareness initiatives.

Recommendations

As the southern marshes of Iraq are a critical refuge for at least eight globally threatened bird species and 26 additional species of birds of conservation concern, it is recommended that:

- Both summer and winter bird population monitoring should continue in the southern marshes (and now in northern Kurdistan KBA sites) of Iraq, to strengthen the reliability of bird data accumulated over the 2005 to 2008 period;
- Long-term monitoring of habitats using bird species as key biological indicators of the health of the southern marshes and other biologically important areas of Iraq

should continue and should be seen as a vital source of biodiversity management information;

- The results of these surveys should be used to help in the appraisal of the recovery of the southern marshes in general and for these bird species in particular;
- The results of these surveys should be used to facilitate identification of protected areas and local community-based biodiversity management programs that can assist in establishing economic opportunities for those communities; and
- Monitoring of bird species and key habitat areas through the further extension of the KBA Project into additional areas of Iraq (as now being done in Kurdistan in northern Iraq) should be considered when it is feasible and safe.

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References

Abdulhasan NA, Salim MA (2008) Key Biodiversity Survey of Southern Iraq. A. Bachmann, J. Davies and L.R. Malone (Eds) Field Report. Sulaimani, Kurdistan, Iraq: Nature Iraq.

Allouse B (1953) Avifauna of Iraq. Baghdad, Iraq: Al-Tafyudh Press.

Allouse B (1962) Birds of Iraq Vol. I-II. (in Arabic). Baghdad, Iraq: Al-Rabita Press.

Ararat K, Abid IM, Rahman SA (2008) Key Biodiversity Survey of Kurdistan, Northern Iraq. A Bachmann, J Davies and LR Malone (eds.). Field Report. Sulaimani, Kurdistan, Iraq: Nature Iraq.

BirdLife International (2000) Threatened Birds of the World. Barcelona, Spain and Cambridge, United Kingdom.

Evans MI (1994) Important Bird Areas in the Middle East, BirdLife Conservation Series No. 2. Cambridge, United Kingdom: BirdLife International.

George PV, Vielliard J (1970) Midwinter Observations on Birds of Central and South Iraq, 1968. Baghdad, Iraq: Iraq Natural History Museum Bull. Vol. IV (4).

Hussain NA Personal communication. Basrah, Iraq: Department of Biology, College of Science, University of Basrah.

Mullarney K, Svensson L, Zetterstrom D, Grant PJ (1999) Collins Bird Guide. London, United Kingdom: Collins Publishing.

Nature Iraq (2007) Key Biodiversity Areas, Kurdistan, Northern Iraq Winter 2007. A Preliminary Report. Sulaimani, Kurdistan Iraq: Nature Iraq.

Porter RF, Scott DA (2005) Report on the Environmental Training Programme for Iraqis and Birds Recorded in Syria – January 20–29, 2005. Canada-Iraq Marshlands Initiative Technical Report No. 3. Waterloo. Canada: University of Waterloo.

Porter RF, Christensen S, Schiermacker-Hansen P (1996) Field Guide to the Birds of the Middle East. Helm Field Guides. United Kingdom, A&C Black Publishers Ltd. London.

Porter RF, Christensen S, Schiermacker-Hansen P (2006) Field Guide to the Birds of the Middle East (in Arabic). Beirut, Lebanon: Society for the Protection of Nature in Lebanon.

Rubec CDA, Bachmann A (2009) The Key Biodiversity Areas Program in Iraq: Objectives and Scope 2004–2008. Project Report. Sulaimani, Kurdistan, Iraq: Nature Iraq.

Salim MA (2004a) I: Field Observations on Birds at Abu-Zarag and Kirmashiya Wetlands, Southern Iraq, 30 June – 4 July 2004. Project Report. Baghdad, Iraq: Nature Iraq.

Salim MA (2004b) II: Field Observations on Birds in Abu-Zarag and Kirmashiyah Wetlands, Southern Iraq, 24 – 28 July 2004. Project Report. Baghdad, Iraq: Nature Iraq.

Salim MA (2004c) III: Field Observations on Birds in Iraq since 1990 Project Report. Baghdad, Iraq: Nature Iraq.

Salim M, Porter RF, Christensen S, Schiermacker-Hansen P, Jbour S (2006) Birds of Iraq. Amman Jordan: Nature Iraq and BirdLife International. (In Arabic).

Scott DA (1995) A Directory of Wetlands of the Middle East. Slimbridge, United Kingdom: International Waterfowl and Wetlands Research Bureau.

Scott DA, Carp E (1982) A midwinter survey of wetlands in Mesopotamia, Iraq: 1979. Sandgrouse No. 4.