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Restoring the Garden of Eden: An Ecological Assessment of the Marshes of Iraq

CURTIS J. RICHARDSON AND NAJAH A. HUSSAIN

The Mesopotamian marshes of southern Iraq had been all but destroyed by Saddam Hussein's regime by the year 2000. Earlier assessments suggested that poor water quality, the presence of toxic materials, and high saline soil conditions in the drained marshes would prevent their ecological restoration and doom the reestablishment of the Marsh Arab culture of fishing and agriculture. However, the high volume of good-quality water entering the marshes from the Tigris and Euphrates Rivers, a result of two record years of snowpack melt in Turkey and Iran, allowed 39% of the former marshes to be reflooded by September 2005. Although reflooding does not guarantee restoration success, our recent field surveys have found a remarkable rate of reestablishment of native macroinvertebrates, macrophytes, fish, and birds in reflooded marshes. However, the future availability of water for restoration is in question, which suggests that only a portion of the former marshes may be restored. Also, landscape connectivity between marshes is greatly reduced, causing concern about local species extinctions and lower diversity in isolated wetlands.

Keywords: functional assessment, Iraq, Mesopotamia, restoration, wetlands

Many consider Iraq's Mesopotamian marshes (figure 1a)—often referred to as the "Garden of Eden"—to have been the cradle of Western civilization (Thesiger 1964, Nicholson and Clark 2002). The word *Mesopotamia* means "between rivers," referring to the location between the Tigris and the Euphrates. These marshes were once the largest wetlands in southwest Asia and covered more than 15,000 square kilometers (km^2), an area nearly twice the size of the original Everglades. However, as a result of a systematic plan by Saddam Hussein's regime to ditch, dike, and drain the marshes of southern Iraq, less than 10% of the area remained as functioning marshland by the year 2000 (figure 1b; Partow 2001, Brasington 2002). The only remaining marsh of any size was the northern portion of Al-Hawizeh (figure 1a, site 1), which straddles the border between Iran and Iraq. The other two marshes, Central (also locally known as the Qurna marsh with the largest lakes; figure 1a, site 2) and Al-Hammar (figure 1a, site 3), were virtually destroyed by 2000. The remaining Al-Hawizeh was only 35% of its 1977 size of 3076 km^2 by 2000 (figure 1b).

The loss of these ecologically critical wetlands was of added concern because they were once home to 300,000 to 500,000 indigenous Marsh Arabs (Young 1977, Coast 2002). In 1991, at the end of the first Gulf War, a populist uprising by the Shi'a (the largest Muslim sect in Iraq) was crushed with brutal force by the Sunni-controlled Baghdad regime. The military raided settlements, killed at least tens of thousands of Marsh Arabs—the actual number may be much higher—burned settlements, killed livestock, and destroyed the core of the local economy. The agricultural and fishing livelihood of the Marsh Arabs was shattered. Persecuted and with no sustenance, tens of thousands were moved to the edges of the drained marshes or to the desert. More than 75,000 Marsh Arabs fled to southern Iran and lived there in refugee camps for over 10 years until Saddam's regime fell (Nicholson and Clark 2002).

Most of the refugees had returned to Iraq by the end of 2004, but they found few viable marshes remaining. They had virtually no chance of earning a traditional living by fishing and raising water buffalo. Today, the Marsh Arab population living near the marshes is estimated to be between 75,000 and 85,000, and those living actually within the marshes probably number fewer than 10,000 (DAI 2004). The remainder are scattered in villages throughout the desert or are refugees in the larger cities.

The marshes were also once famous for their biodiversity and cultural richness. They were the permanent habitat for millions of birds and a flyway for millions more migrating between Siberia and Africa (Maltby 1994, Evans 2002). More

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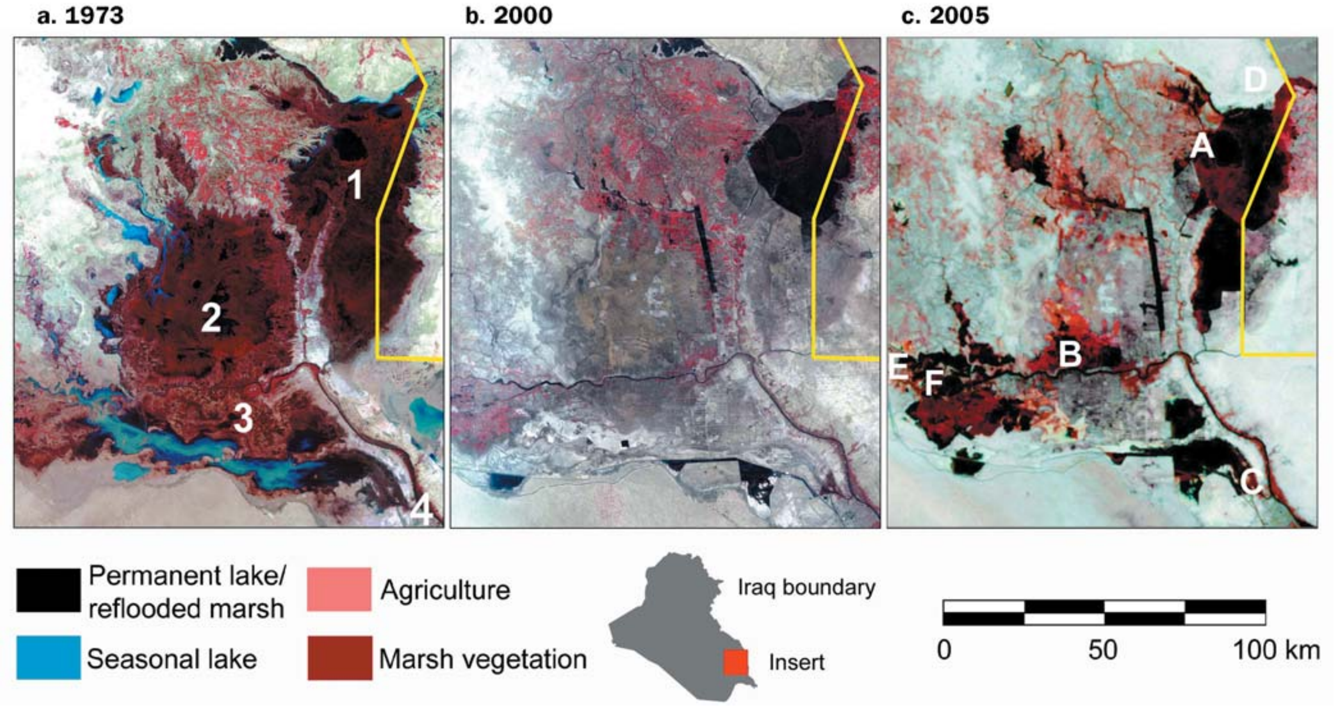

Figure 1. (a) A composite view of the Mesopotamian marshlands from a mosaic of four Landsat 1 images and two false-color, near-infrared images, 1973–1976. Dense marsh vegetation (mainly* Phragmites australis*) appears in dark red, seasonal lakes in blue, agriculture in pink, and permanent lakes in black. The red elongated patches along riverbanks are date palms. The three main marsh areas are Al-Hawizeh, Central, and Al-Hammar, labeled 1, 2, and 3, respectively. The city of Basrah is located at number 4. Modified from Richardson and colleagues (2005). (b) A Landsat 7 Enhanced Thematic Mapper mosaic taken in 2000. Most of the drained marshes appear as grayish-brown patches, indicating dead marsh vegetation or low desert shrubs and dry ground. The white and gray patches indicate bare areas with no vegetation and, in some areas, salt evaporites or shells covering the bottoms of former lakes. By 2000, 85% of the 8926 square kilometers (km^2) of permanent marsh in 1973 marshlands had been destroyed. Only 3% of the Central marsh and 14.5% of the Al-Hammar remained. A canal known as the Glory River (shown as a straight line across the top and down the east side of the Central marsh), constructed in 1993, completely dried up the Central marsh by stopping water inflow from the Tigris River. The largest expanse (approximately 1025 km^2) of remaining natural marsh, the Al-Hawizeh, near the Iranian border, is shown in dark red. Modified from Richardson and colleagues (2005). (c) False-color image of the remaining Mesopotamian marshlands, taken 2 September 2005, shows in black the areas newly reflooded since the war. Reflooded areas adjacent to Al-Hawizeh, the western area of Al-Hammar, and waterways in the northern and southern parts of the Central marsh are also visible in black. Al-Hawizeh (called Hawr Al-Azim in Iran) is the best remaining natural marsh in the region. It straddles the Iraq–Iran border (yellow line). During a field survey in February 2004, we discovered an Iranian dike under construction that is now nearly completed and will traverse directly through the Al-Hawizeh marsh, along the Iraq–Iran border, and, as a result, will significantly reduce the water input from the Karkheh and Karun rivers to the marsh. The ecological affects of this massive water diversion are unknown, but it will significantly affect the last remaining natural marsh system in Iraq. Sampling sites: A, Al-Hawizeh; B, Central; C, Al-Hammar; D, Al-Sanaf; E, Abu Zarag; F, Suq Al-Shuyukh. MODIS satellite image courtesy of the United Nations Environment Programme, Iraq Marshlands Observation System.

than 80 bird species were found in the marshes in the last complete census in the 1970s (Evans 2002). Populations of rare species such as the marbled teal (*Marmaronetta angustirostris;* 40% to 60% of the world population) and the Basrah reed warbler (*Acrocephalus griseldis;* more than 90% of the world population), which had been thought close to extinction (Evans 2002), were recently seen in a winter bird survey (figure 2; Salmin et al. 2005). Coastal fish populations in the Persian Gulf used the marshlands for spawning migrations, and the marshes also served as nursery grounds for penaeid shrimp (*Metapenaeus affinis*) and numerous marine fish species. Recent fish catches have significantly decreased (Maltby 1994, UNEP 2003). The marshlands also once served as a natural filter for waste and other pollutants in the Tigris and Euphrates rivers, thus protecting the Persian Gulf, which has now become noticeably degraded along the coast of Kuwait (Maltby 1994, Saeed et al. 1999, Partow 2001).

Although the Mesopotamian marshes had been almost completely destroyed, it became clear on first inspection that they were restorable, since they are a true "river of grass,"

*Figure 2. Two globally vulnerable species, marbled teal (***Marmaronetta angustirostris***, left) and Basrah reed warbler (***Acrocephalus griseldis***, right), photographed in 2005 in the Iraq marshes by Iraqi nature photographer Al Salim. Photographs courtesy of the Canadian International Development Agency and Mudhafar A. Salim (***www.cimiwetlands.net***).*

wetlands fed by rivers and dominated by the aquatic grass *Phragmites australis.* The first assessment of the status of the marshes was done almost immediately after the fall of Baghdad in June 2003 by a team of US scientists, who found that massive but uncoordinated reflooding of the marshes was occurring (Richardson et al. 2005). This early field analysis concluded that water quantity and quality were sufficient to restore some areas of the marshes and that a rapid reestablishment of native plant species was occurring in some areas. Still, many serious questions about the potential for restoration remained:

- What are the problems that could result from uncontrolled reflooding of drained former marshes?
- How serious are the problems of water quality (high levels of pollutants, ions such as sodium [Na^{+1}]) and soil toxicity (sulfide, sodic soils), which may prevent marsh restoration?
- Can the native flora and fauna, including rare or endangered species, reestablish in marshes that had been drained for over a decade and isolated from native populations?
- Could marsh health be assessed accurately after only two years of reflooding?
- Will there be enough water to restore the marshes, given competing national and international demands on water?
- Most important, would the Marsh Arabs return to live once more in the marshes, given the complexity of resettlement problems?

The objectives of this article are to update some of our earlier findings by analyzing the last two years of field data collected by US and Iraqi scientists and to provide new answers, where possible, to the questions above.

An approach for assessing marsh restoration

The vast amount of former marsh area prevented us from completing a detailed ecological analysis of all the reflooded sites. To cover the three historic marsh areas (Central, Al-Hawizeh, and Al-Hammar), we selected four very large marshes: Al-Hawizeh, the only natural remaining marsh on the Iranian border; the eastern Al-Hammar marsh; Abu Zarag (western Central marsh); and Suq Al-Shuyukh (western Al-Hammar) (figure 3). From 2003 until 2005, we monitored water quality, water depth and transparency, soil chemistry conditions, and ecological indicators of plant and algal productivity, and we surveyed the numbers and species of birds, fish, and macroinvertebrate populations. (For a detailed analysis of the field and laboratory chemistry methods and statistical analyses used in this article, see DAI 2004, Richardson et al. 2005.) This original work was done in conjunction with Iraqi scientists to assess the ecological and environmental conditions present where the dominant flora and fauna in the natural Al-Hawizeh still existed and to compare these conditions with those of three marshes reflooded in 2003. To provide an estimate of overall ecosystem health, we completed an ecosystem functional assessment (EFA) to determine restoration progress to date and to establish how the newly reflooded marshes were functioning compared with the natural marsh and with historical values.

In the EFA method, indicators of ecosystem function are grouped into five ecosystem-level functional categories: hydrologic flux and storage, biological productivity, biogeochemical cycling and storage, decomposition, and community/wildlife habitat (Nunnery 1997, Richardson and Nunnery 2001). Next, a carefully chosen set of variables representing these five functional categories are selected as key indicators to be measured in the affected ecosystems and in a set of reference ecosystems. Key indicator values obtained in the field from the affected ecosystem are scaled against those from reference ecosystems to determine whether there are significant shifts in these indicators (Richardson and Nunnery 2001, Richardson et al. 2003, Richardson 2005). Our EFA analysis of the marshes was somewhat compromised in terms of the collection of the most appropriate key indicators for each function because of the difficulty of sampling in remote and dangerous areas of Iraq. Thus, our estimates of ecosystem health are less quantitative than a standard EFA. The current research and monitoring is being carried out primarily by two Iraqi research teams from the University of Basrah, supported by the US Agency for International Development (USAID), and by the New Eden project, supported by Italian government funds and the Canadian International Development Agency. The total international funding to date for marsh restoration is slightly in excess of $30 million, a minuscule amount compared with the billions being spent in Iraq for other purposes.

Problems with marsh reflooding

Almost immediately after the collapse of the Hussein regime in April 2003, local farmers and water ministries began blowing up dikes and earthen dams or otherwise releasing water back into the former marsh areas through control structures. (See figure 1c for reflooded areas; ground views of the natural, reflooded, diked, and drained sites are shown in figure 3.) By February 2004, nearly 20% of the 15,000 km^2 of the former drained marshes had been reflooded. More recent estimates from the Iraq Water Ministry and from UNEP (United Nations Environment Programme) satellite photos indicate that by 2005, 39% of the destroyed marshes had standing water; also noteworthy, a trend analysis of vegetation regrowth from January 2003 until September 2005 indicated that vegetation cover was expanding at 800 km^2 per year (UNEP

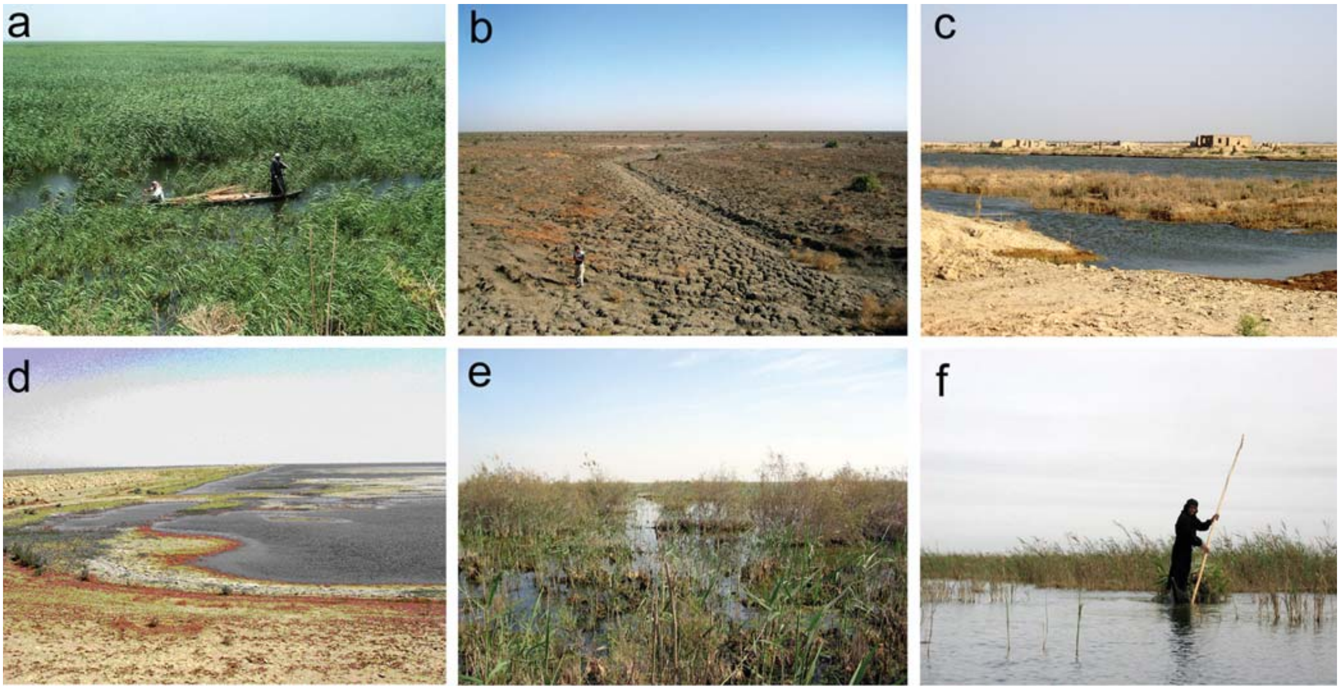

*Figure 3. (a) Marsh Arab fishermen collecting reeds (*Phragmites australis*) in the natural Al-Hawizeh marsh (N 31°38.583, E 47°35.203) near the Iranian border in June 2003. (b) The totally drained Central marsh near Chibayish (N 30°58.102, E 47°09.033) in June 2003. An Iraqi engineer from the Ministry of Water Resources is viewing the cracked and desiccated marsh soil adjacent to a dried-out streambed. (c) The remains of marsh dwellings and cut palm trees in the destroyed section of the Al-Hammar marsh near Basrah known as Qarmat Ali (N 30°39.561, W 47°39.230). The area was reflooded in April 2003 when local tribes broke the earthen dam holding out the water for this section of the marsh. (d) Al-Sanaf, a seasonal marsh area (N 31°92.491, E 47°12.674) that is used to take overflow water from the Crown of Battles River. It has extremely high salinities (see table 1) and ion concentrations, including toxic levels of selenium, due to a lack of proper outflow drainage and high evapotranspiration (Richardson et al. 2005). High ion concentrations have prevented the establishment of native marsh vegetation. (e) Abu Zarag in February 2004 (N 31°07.583, E 46°37.422). This area was reflooded in April 2003. The area has seen a rapid recovery of marsh vegetation and algae. Fishing was good in the spring of 2004 and 2005. (f) A Marsh Arab woman collecting reeds for fodder near her island village in Suq Al-Shuyukh in February 2004 (N 30°51.491, E 46°40.398). This marsh was among the earliest to be reflooded, in early 2003, and has excellent reed regrowth; thus, it is the major location where Marsh Arabs have returned to live on traditional "floating islands" with their water buffalo (*Bubalus arnee*). Photographs: Curtis J. Richardson.*

2005). However, wetland habitat fragmentation (disconnected patches), one of the most commonly cited causes of species extinction (Wiens 1996), and ensuing loss of biological diversity are quite evident when surveying the distance between reflooded marshes (figure 1c). The sparsely vegetated reflooded areas are very scattered compared with the contiguous wetland landscape found in 1973 (figure 1a; Al-Hilli 1977). In addition, many of the former water flow connections between marsh patches are now blocked by dikes and canals. Landscape connectivity, the inverse of landscape fragmentation (Urban and Keitt 2001), is now considerably reduced, which can have significant effects on population survival (Fahrig and Paloheimo 1988) and metapopulation dynamics (Levins 1970) for macroinvertebrates, fish, amphibians, and even plants.

Although the uncontrolled reflooding is welcome news, it presents potential problems and challenges regarding the quality of water:

- The release of toxins from reflooded soils that are contaminated with chemicals, mines, and military ordnance
- Flooding of local villages and farms now developed on the edges of formerly drained marshes
- A false sense of security regarding the volume of water that will be available to restore the marshes in future years

All these problems have come to light in the past two years. Toxic levels of sulfides and salts have been reported in a few areas of the reflooded marshes (Fitzpatrick 2004, Richardson et al. 2005). Minefields exist throughout the marshes along the border of Iran, and a number of villages were flooded by the destruction of dikes and dams (C. J. R., personal observation). Marsh restoration has been further complicated by the construction of more than 30 dams and several thousand kilometers of dikes in Iraq during the past 30 years. This infrastructure has resulted in the retention of large volumes of water in the central portions of Iraq for cities and agriculture, as well as in the reduction of new sediment accumulation in the marshes (Partow 2001, Nicholson and Clark 2002). During the past two years, high snowmelt from the mountains of Turkey and Iran has resulted in near record flows on the Tigris and Euphrates rivers, resulting in vast amounts of excess water being available for reflooding of the marshes (Partow 2001, Richardson et al. 2005), but it is unknown how long this pattern of increased water release will last.

Another issue that is not clearly understood by many engineers and water managers is that reflooding does not equal wetland restoration. While the presence of adequate water is critical to marsh restoration, the restoration of wetland functions requires also the proper water hydroperiod (period of time water is at or near the surface), hydropattern (distribution of water over the landscape), and good water quality. These conditions are complex in nature. Restoration projects that do not take this complexity into account can at first seem to be successful, but they are later recognized as failures because conditions promoting important ecosystem functions have not been adequately restored (Zedler and Calloway 1999, Richardson and Nunnery 2001). For example, in historic times the pulsed flow of water, sediments, and nutrients into the Iraqi marshes came via the spring melt. Massive flooding was the most common condition during this period, with marsh expansion from 15,000 to 20,000 km^2, followed by a decrease in marsh area by as much as 30% to 50% during the summer as a result of high evaporation rates (> 200 centimeters [cm] per year; Buringh 1960). During the summer, the Marsh Arabs planted their rice and barley crops at the marsh edges and used the annually rejuvenated marsh soils to produce their crops. The water flow was continuous through the year, and it was this flow that kept the salinity concentrations low and prevented the buildup of potentially toxic elements, such as selenium and salts, that was seen in the diked areas of Al-Sanaf (figure 4; Richardson et al. 2005). Now, dams, dikes, and canals prevent the overflow of water at the marsh edges, thus reducing the historical inundation pattern of the marshes.

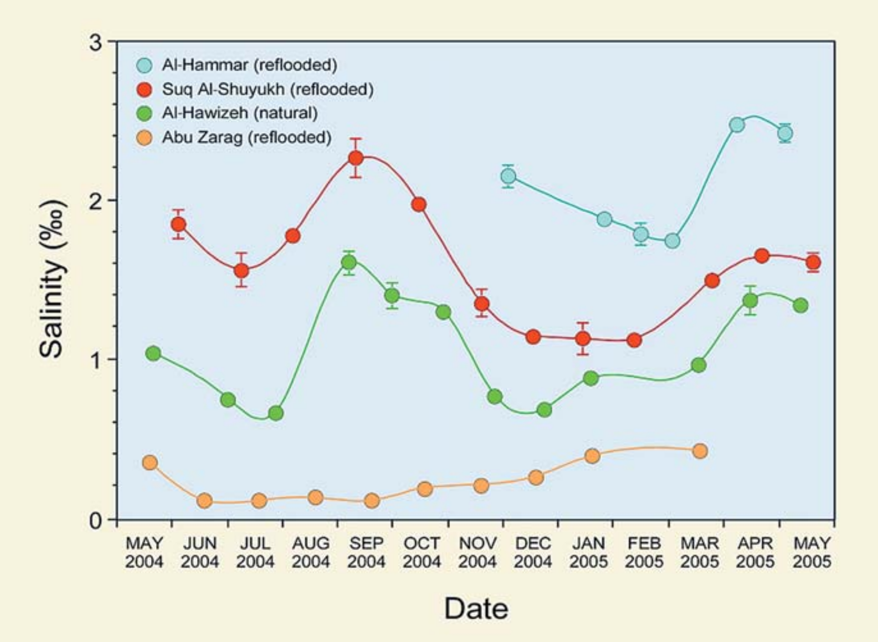

Figure 4. A monthly comparison of salinity patterns in the natural Al-Hawizeh marsh and in three reflooded marshes (Al-Hammar, Suq Al-Shuyukh, and Abu Zarag) after 12 to 18 months of water additions. Data are from researchers from the University of Basrah and the Eden Again Project.

Water quality and soil chemistry conditions

The idea that only 15% to 20% of the drained wetland could be restored because of excessive salinity, environmental pollution, a lack of available high-quality water, or a loss of native species (Partow 2001, EA ITAP 2003) was quickly dispelled by our 2003 and 2004 field surveys (Richardson et al. 2005). Water quality in the Tigris and Euphrates, which flow into the marshes, was much better than earlier thought (table 1). The natural Al-Hawizeh marsh (figure 3a) had the lowest concentration for all major ions, and the total phosphorus (P) in surface water was close to river water values (table 1). Dissolved organic carbon was highest in the drained and highly oxidized marsh outflows, while the natural site and river waters demonstrated much lower values. The reflooded eastern Al-Hammar site (figure 3c) had the highest total P, which may be related to sampling at several sites where human and animal waste was released directly into the water column without treatment. Total nitrogen was highest at the Al-Sanaf site (figure 3d), an area where nitrogen-fixing blue-green algae were seen to be dominant in the water column, even at higher salinities (Al-Mousawi and Whitton 1983). All upstream and marsh surface waters were highly oxygenated, but oxygen was significantly reduced ($P < 0.05$) in the Shatt Al-Arab, where untreated wastewater is currently being released from cities such as Basrah. Salinity, conductivity, and concentrations of total dissolved solids (TDS) were low, and pH was between 7 and 8 at all sites except for the enclosed Al-Sanaf, where these variables were significantly higher ($P < 0.05$). The restricted water outflows in the Al-Sanaf, coupled with high regional evapotranspiration rates, have resulted in extremely high ion concentrations, pH, and TDS (table 1), values similar to those measured in highly salinized portions of the Jordan River (Farber et al. 2004). Results from Al-Sanaf suggest that simply adding water to former marshes without providing for continual flushing will result in excessive salinity and toxicity problems (Richardson et al. 2005).

Fortunately, a year-long survey of the salinity of the three restored marshes, when compared with the natural Al-Hawizeh, indicates that these restored areas are maintaining very low salinities after nearly two years of reflooding (figure 4). Salinities generally showed a seasonal summer peak due to high evapotranspiration but were below 3 parts per thousand (ppt). The two lowest areas of salinity, the natural Al-Hawizeh and Abu Zarag, both have lower-salinity Tigris water as their source, compared with the higher-salinity Euphrates, which feeds the other two sites. Al-Hammar had the highest concentrations of most constituents, which indicates that this reflooded site is more saline and chemically enriched than the other two sites, since it now receives tidal seawater from the Persian Gulf (Richardson et al. 2005). However, our current water chemistry values, when compared with historical surveys completed before drainage in the Al-Hammar marsh (Maulood et al. 1981, Banat et al. 2005), revealed an increase in conductivity (240%), TDS (140%), Na^{+1} (170%), magnesium (Mg^{+2}; 158%), calcium (Ca^{+2}; 240%), chlorine (Cl^{-1}; 160%) and bicarbonate (HCO_3^-; 180%) in the Suq Al-Shuyukh region during the past 20 years (Richardson et al. 2005). In contrast, measured salinities in 1981 (Maulood et al. 1981) from seven locations in the undrained Central marsh averaged 0.6 ppt (± 0.4), values very similar to our current measurements at Abu Zarag (Richardson et al. 2005).

Worldwide, the highest numbers of species are found in aquatic environments below a salinity of 5 ppt (Wetzel 2001). Collectively, our studies indicate that the reflooded portions of the western Al-Hammar at Suq Al-Shuyukh and eastern Al-Hammar have experienced increases in saline conditions but are still well below the concentrations that affect most

Table 1. Water quality at selected river and marsh locations in southeast Iraq, June 2003.

Constituent	Upstream Tigris and Euphrates (rivers)		Al-Hawizeh (natural marsh)		Al-Hammar (reflooded marsh)		Al-Sanaf (reflooded marsh)		Downstream Shatt Al-Arab (river)	
Salinity (ppt)	0.77^{b}	(0.05)	0.87^{b}	(0.04)	0.96^{b}	(0.03)	17.49^{a}	(0.45)	2.13^{b}	(1.4)
Conductivity (mS per cm)	1.55^{b}	(0.11)	1.74^{b}	(0.06)	1.91^{b}	(0.06)	28.41^{a}	(0.61)	4.10^{b}	(2.45)
pH	8.14^{b}	(0.09)	7.64^{b}	(0.16)	7.95^{b}	(0.06)	9.40^{a}	(0.01)	7.51^{b}	(1.01)
Dissolved oxygen (mg per L)	8.11^{a}	(1.67)	7.71^{a}	(1.39)	7.03^{a}	(0.06)	8.79^{a}	(0.67)	4.89^{b}	(1.19)
Total dissolved solids (g per L)	1.01^{b}	(0.07)	1.13^{b}	(0.04)	1.24^{b}	(0.04)	18.46^{a}	(0.40)	3.02^{b}	(2.07)
Total nitrogen (µg per L)	763^{b}	(470)	464^{b}	(0.04)	$1,652^{ab}$	(546)	$2,050^{a}$	(205)	849^{b}	(103)
Total phosphorus (µg per L)	112^{a}	(47)	133^{a}	(27)	657^{a}	(1174)	93^{a}	(22)	147^{a}	(38)
Dissolved organic carbon (mg per L)	4.79^{b}	(2.10)	4.68^{b}	(0.70)	13.92^{b}	(7.91)	37.86^{a}	(1.00)	4.95^{b}	(1.10)

cm, centimeter; g, gram; L, liter; mg, milligram; µg, microgram; mS, millisiemens; ppt, parts per thousand.

Note: Different letters indicate a significant difference ($P < 0.05$) across sites and the same letter indicates no significant difference among sites as determined by least significant difference test. Standard errors of the mean are shown in parentheses.

freshwater species. The long-term rates of salinity increases are unknown, but present levels are within the normal variation found in the marshes between the wet season and the dry season (Al-Hilli 1977, Hussain 1992, Richardson et al. 2005). The cause for this increase in salinity is unknown, but it probably relates to a rise in salinity in the Euphrates and to increased flux into the water column of ions concentrated in the soil after 10 years of drainage and evaporation. In the case of eastern Al-Hammar, breaches in dikes in 2003 allowed more tidal seawater to flow from the Shatt Al-Arab into the marsh.

Analyses of surface water and soils for organochlorine pesticides, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons (PAHs) showed no detectable concentrations of any of these xenobiotics (Richardson et al. 2005). However, recent surveys in Abu Zarag have found low molecular weights of PAHs in Abu Zarag soils, probably as a result of the severe burnings in the region (DouAbul et al. 2005). These findings are in contrast to earlier reports of higher chemical pollution in the marshes and rivers (DouAbul et al. 1988, Saeed et al. 1999) and probably reflect the lack of pesticide use in the drained marshes, reduced chemical releases into water bodies during the war, or our limited sampling regime. Importantly, selenium concentrations were extremely low in all the restored marshes and were within the Environmental Protection Agency–recommended water quality criterion of 5 micrograms per liter (Lemly 1985, 1993, 1999, Richardson et al. 2005).

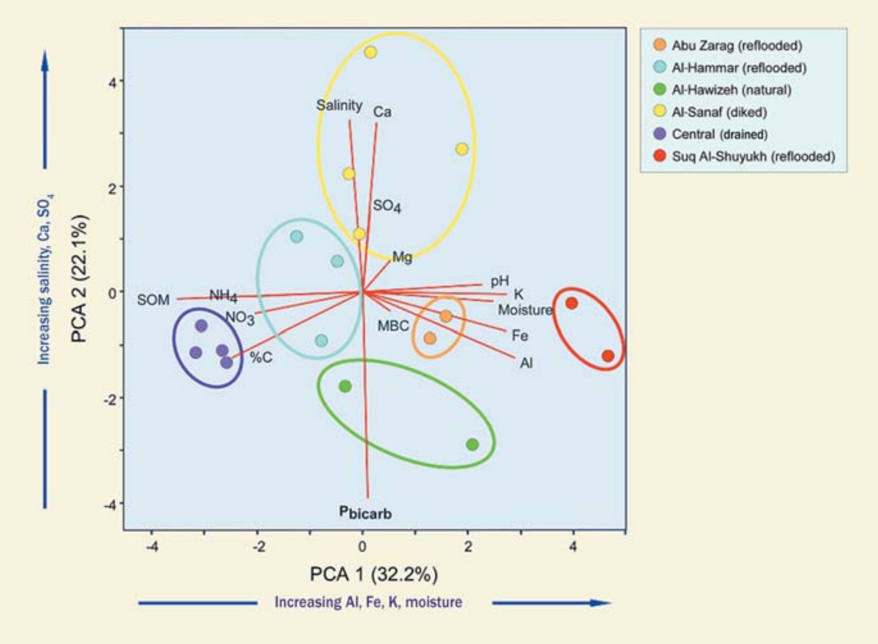

Figure 5. A principal component analysis (PCA) of the marsh soils from drained (Central), diked (Al-Sanaf), restored (Abu Zarag, Suq Al-Shuyukh, Al-Hammar), and natural (Al-Hawizeh) marshes of southern Iraq. Axis 1 accounted for 32.2%, axis 2 accounted for 22.1%, and axis 3 accounted for 16.9% of the total variance (not shown). Soil properties with strong negative loadings on axis 1 included percentage of carbon (%C), soil organic matter (SOM), and nitrogen species, while extractable aluminum (Al) and iron (Fe) as well as well as soil moisture, potassium (K), and pH had a strong positive loading on axis 1. A number of soil properties, including salinity, sulfate (SO_4), and exchangeable calcium (Ca), had strong positive loadings on axis 2 and showed distinct differences among marsh sites, especially between the Al-Sanaf and the natural Al-Hawizeh. The highest extractable phosphorus (bicarbonate; P_{bicarb}) was found in the natural Al-Hawizeh. Abbreviations: MBC, microbial biomass carbon; Mg, magnesium; NH_4, ammonium; NO_3, nitrate.

Large differences occur in the physical and chemical characteristics of the natural, diked, drained, and reflooded marsh soils as shown with principal component analysis (PCA; figure 5). The first three principal component axes were significant, according to the broken-stick eigenvalue test (Legendre and Legendre 1998), and together they accounted for 71% of the variance in the data. The PCA revealed that marsh alteration may have resulted in significant changes in soil chemistry and moisture, with the reflooded but diked Al-Sanaf marsh having much higher salinities, higher sulfate (SO_4) levels, and lower soil moisture than the natural marsh site. Surprisingly, the Central marsh still retained the highest soil organic matter after more than 10 years of drainage and extensive fires. The soil chemistry of the reflooded Al-Hammar marshes had higher salinities than the other restored sites, which, as mentioned earlier, reflects the influence of tidal water input. The restored sites at Suq Al-Shuyukh and Abu Zarag and the natural Al-Hawizeh sites were found in the same general ordination space, with more soil moisture, higher exchangeable P, and increased microbial biomass carbon. Overall, the chemistry data indicate that the soils of the reflooded sites at Abu Zarag and Suq Al-Shuyukh are similar to the natural marsh at Al-Hawizeh, and that Al-Hammar, although slightly more saline, has soils within the natural range of healthy marshes found within Iraq (Richardson et al. 2005). (Importantly, some of the chemical differences measured among marsh sites are due to variations in soil type and geology found across southern Iraq, and thus not all of the variations can be attributed to drainage; Buringh 1960.)

However, restoration may be difficult in some localized areas, because soil conditions and water quality in the drained and diked (as compared with the reflooded and natural) marshes clearly demonstrated massive shifts in ion chemistry and structure. For example, many areas of the marshes were severely burned after drainage. The intensity of the burns in some areas, with high surface organic matter covering sulfidic pyrite soils beneath, resulted in soils being greatly altered chemically and then exposed to oxygen for decades of draining, resulting in the formation of sulfuric acid (Fitzpatrick 2004). These highly oxidizing conditions liberate iron (Fe), Ca, Mg, and trace elements like copper as well as producing toxic conditions and sodic or calcic soils when reflooded. Moreover, Fitzpatrick's X-ray scanning electron microscopy work (2004) suggests that the burned soils where iron sulfide (FeS_2) has been converted to iron oxide maghermite (Fe_2O_3) now have a texture like ceramic, meaning that the soil will not rewet and cannot support plant life. The soil chemistry analysis results suggest that reflooded and drained marsh areas can be restored, but some locations will have excessive salt accumulation problems, toxic elements, and severe water quality degradation, with a concomitant loss of native marsh vegetation. It is imperative that these areas be identified so that the limited water supplies can be used to restore those areas with the most promise for full restoration.

Ecological recovery of native flora and fauna

One year after reflooding, species recovery was occurring in all three former marshland sites (Abu Zarag, Al-Hammar, and Suq Al-Shuyukh), but with varying degrees of success and at different successional rates (Richardson et al. 2005). A biotic 2004–2005 survey from the Al-Hammar and Suq Al-Shuyukh marshes indicated that most macrophyte, macroinvertebrate, fish, and bird species were returning to the restored marshes, although densities were low compared with historical records (figure 6). The reason for the early return of many species is probably directly related to the reintroduction of propagules, seeds, larvae, and fish stocks directly from the overflow river waters of the Tigris and Euphrates. A listing of the five most common species of plants, birds, and fish found in Al-Hawizeh as compared with Suq Al-Shuyukh and Al-Hammar reveals that Al-Hammar and Suq Al-Shuyukh are most similar, while Al-Hammar differs from the other two marshes in dominant species composition (table 2). This difference in species is probably related to the tidal influence (higher salinity) now found in Al-Hammar (figure 4). A full comparison of all species surveyed reveals slightly different trends.

Al-Hawizeh had the lowest number of dominant macrophyte species (6) and was dominated by *P. australis* stands and hornwort (*Ceratophyllum demersum*) in the open water areas (figure 3a), whereas Al-Hammar had nearly double the number of plant species (10) as a result of the influence of more salt-tolerant plants (figure 6). Collectively, the restored sites had 15 species, a number close to historic values; however, a number of nondominant species found by Al-Hilli (1977) in his extensive survey of the marshes have not been recorded in recent studies (figure 6). Surprisingly, a Jaccard similarity analysis of all plant species, including nondominants, indicated that Al-Hammar and Suq Al-Shuyukh were most similar to Al-Hawizeh (Jaccard index [C_J] = 0.45 and 0.42, respectively); the macrophytes at Suq Al-Shuyukh were the most dissimilar to those at the natural Al-Hawizeh (C_J = 0.23). Over 100 species of macroinvertebrates were found in the three marshes, and surveys indicate the presence of the main species of arthropods (including crustacea) and mollusks reported in the past (Hussain 1992, Scott 1995), with numbers of individuals per unit area 1.5 times greater at the open-water Suq Al-Shuyukh sites than at the densely vegetated Al-Hawizeh (Richardson et al. 2005). Suq Al-Shuyukh has the highest number of species (more than 60) and Al-Hammar the lowest (42). The highest Jaccard similarity was found between Al-Hawizeh and Suq Al-Shuyukh (C_J = 0.41). All numbers are below historic values. Macroinvertebrate abundances at all marsh sites were dominated by snails (*Lymnaea* spp.) and beetles (Coleoptera).

The highest number of fish species (23), found at Al-Hammar, represented 72% of the historic number (32, including 23 freshwater and 9 estuarine species), and the lowest number (15) were found at Al-Hawizeh (figure 6). The highest Jaccard similarity for fish was found between Al-

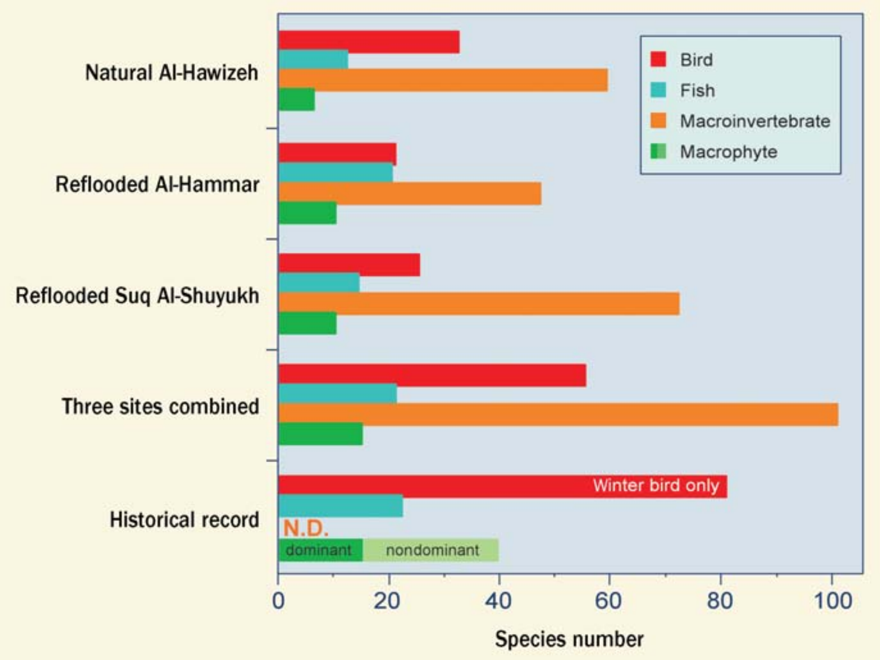

Figure 6. A comparison of numbers of macrophyte, fish, and bird species recorded in one natural marsh (Al-Hawizeh), two reflooded marshes (Al-Hammar and Suq Al-Shuyukh), and current and historical records for all three marshes combined. Current data for macroinvertebrates are presented for comparison among sites, but no reliable historical quantitative records exist for these organisms. Abbreviation: ND, no data.

Table 2. A list of the five most common or abundant species of bird, fish, and plant species in three different marsh areas, based on surveys done by faculty and students at the University of Basrah, 2003–2005.

Al-Hawizeh (natural marsh)	Suq Al-Shuyukh (reflooded marsh)	Al-Hammar (reflooded marsh)
Bird species		
Phalacrocorax pygmeus	*Egretta garzetta*	*Egretta garzetta*
Egretta garzetta	*Ceryle rudis*	*Larus ridibundus*
Tachybaptus ruficollis	*Ardeola ralloides*	*Larus genei*
Larus canus	*Ardea purpurea*	*Larus canus*
Larus ridibundus	*Vanellus leucurus*	*Sterna albifrons*
Fish species		
Barbus luteus	*Liza abu*	*Liza abu*
Aspius vorax	*Carassius carassius*[a]	*Liza carinata*
Carassius carassius[a]	*Barbus luteus*	*Carassius carassius*[a]
Barbus sharpeyi	*Aspius vorax*	*Barbus luteus*
Liza abu	*Alburnus mossulensis*	*Alburnus mossulensis*
Plant species		
Phragmites australis	*Phragmites australis*	*Ceratophyllum demersum*
Ceratophyllum demersum	*Ceratophyllum demersum*	*Myriophyllum verticillatum*
Salvinia natans	*Typha domingensis*	*Phragmites australis*
Lemna minor	*Panicum repens*	*Schoenoplectus littoralis*
Typha domingensis	*Schoenoplectus littoralis*	*Potamogeton pectinatus*

Note: Ranking of species is based on bird counts, fish sampling numbers per catch, and percent cover on 100-meter line transects in each marsh.

a. Nonnative carp species introduced from Iran.

Hawizeh and Suq Al-Shuyukh ($C_J = 0.73$). If marine species were excluded, the similarity value rose to $C_J = 0.94$. The similarity between Al-Hawizeh and Al-Hammar was 0. 65. A more detailed survey of fish species composition and size, assessed in conjunction with local fish market data, indicates that bunni (*Barbus sharpeyi*)—the most important historic endemic fish species with the highest commercial value—is present in all the marshes, but in greatly reduced numbers and size (Richardson et al. 2005). *Carassius carassius,* an introduced carp species from Iran, comprised 20% of the summer 2004 catch in Suq Al-Shuyukh but up to 46% of the catch in Al-Hawizeh. A survey of the fishermen of the villages (DAI 2004) also indicated that fishing is extremely poor because of the small size of the fish and because *Silurus triostegus,* a carnivorous catfish species (40 to 55 cm in length) not eaten by the local Shi'a population for religious reasons, can comprise up to 60% (by weight) of the catch. The current domination by a piscivorous species like *Silurus* rather than herbivorous *Barbus* species is also due in part to prolonged marsh drying and a lack of food resources (algae, aquatic plants, and macroinvertebrates) for the herbivorous fish species. The result is an imbalanced fish pyramid, which may have serious impacts on any attempts to restore normal fish population structure in the marshes. The return of marketable fish to the marshes is critical to the livelihood of the Marsh Arabs and the establishment of successful new villages in the interior of the marsh. This is one of the main reasons to date why village resettlement of the marshes has occurred in only a few locations, such as Suq Al-Shuyukh. In March 2004, fishermen reported to us that their livelihood from fishing at that time was very poor, but conditions improved slightly by the summer of 2005. Work is currently under way through USAID to provide fish stocks for the marshes through an aquaculture program (DAI 2004).

The bird survey in the three marshes in 2004 found a total of 56 species, compared with historical counts of 84 species (Scott 1995). The natural Al-Hawizeh marsh had the most species (53), nearly matching our total count of 56 for all the marshes surveyed (figure 6). Al-Hammar had the lowest species number (29), which was slightly more than half the total species identified. The highest Jaccard similarity was found between Al-Hawizeh and Suq Al-Shuyukh ($C_J = 0.64$). Daily summer counts of individual birds per species were low (< 50 birds) except for little egret (*Egretta garzetta*), squacco heron (*Ardeola ralloides*), and the threatened pygmy cormorant (*Phalacrocorax pygmeus*), found in Al-Hawizeh; however, winter counts increased dramatically in the winter of 2005. Importantly, the highly threatened endemic Iraq babbler (*Turdoides altirostris*), a species not seen in a more than a decade, and the marbled teal (*Marmaronetta angustirostris*), another highly threatened species, were seen in the reflooded wetlands, but in low numbers (figure 2). One indication of marsh recovery is that nearly half of the bird species were recorded as breeding in the marshes during the summer of 2004 and 2005. Another indication of bird habitat restoration is that a more complete survey of 28 marsh areas in the winter of 2005, conducted by the Canadian–Iraq Marshlands Initiative, recorded 74 bird species, including 10 rare and endangered species not seen in over 25 years (Salmin et al. 2005).

A functional assessment of ecosystem restoration

We had sufficient data to complete an EFA on only two of the restored marshes. We compared their structure and functions with the remaining natural Al-Hawizeh as well as with recorded historical values for Iraqi marshes (Nunnery 1997, Richardson and Nunnery 1998, 2001, Richardson et al. 2005). In the EFA method, indicators of wetland structure and functions are measured in five ecosystem-level categories: hydrologic flux and storage, biological productivity, biogeochemical cycling and storage, decomposition, and community/wildlife habitat. Because of the difficulty of data collection, we were limited in our ability to use long-term indicators. Given this limitation, we chose metrics best representing the five ecosystem functional categories to give an overall qualitative assessment of marsh functioning.

The EFA analysis revealed that Suq Al-Shuyukh has nearly recovered all its key functions when compared with the remaining natural Al-Hawizeh marsh (e.g., *Phragmites* plant production was 83% of that at Al-Hawizeh, and a crude index of decomposition/redox status as indicated by oxygen in the water column was 93% of the value at the natural marsh), whereas Al-Hammar has severely reduced water transparency (41% of Al-Hawizeh levels) and lower numbers

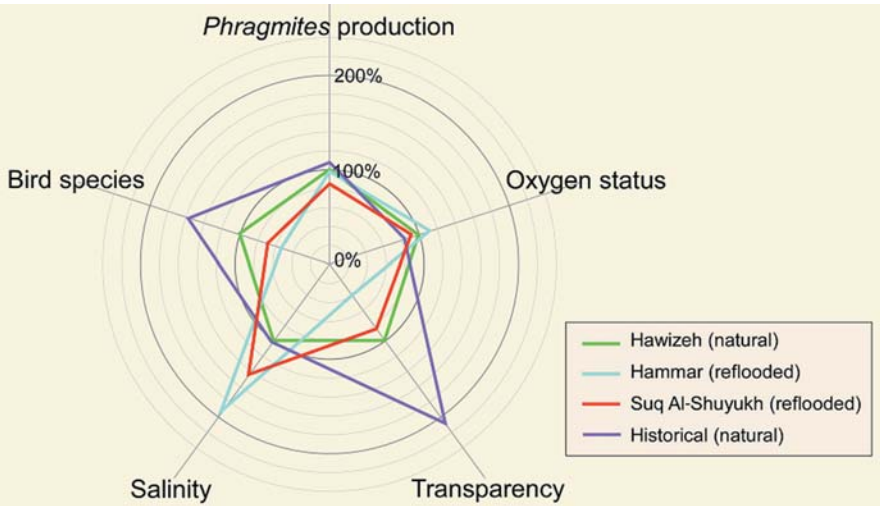

*Figure 7. An ecosystem functional assessment (EFA) utilizing selected indicators of five wetland functions: (1) production (***Phragmites australis*** *aboveground production, in grams per square meter), (2) decomposition/redox status (milligrams of oxygen per liter), (3) hydrologic function (water transparency, or depth of clear water in centimeters), (4) biogeochemistry (salinity, measured as conductivity in millisiemens per centimeter), and community/habitat (bird species number). Figure shows an EFA comparison with the historical Al-Hawizeh values, scaled to 100%, for the two restored marshes (Al-Hammar and Suq Al-Shuyukh) and the remaining natural Al-Hawizeh, and a comparison of all marshes with reported historical values from the 1970s and 1980s. Historical values are from Hussain (1992) for water chemistry and oxygen, from Al-Hilli (1977) for macrophyte production, and from Scott (1995) for birds.*

of bird species (45% of the number at Al-Hawizeh; figure 7). The mean functional difference between Al-Hammar and the natural area (averaged functional differences for all five indicator functions, regardless of sign) was 40%, whereas the mean functional difference for Suq Al-Shuyukh was only 23% (figure 7), indicating that Suq Al-Shuyukh was closest to Al-Hawizeh in overall ecosystem function. The reflooded Al-Hammar's greater deviation from the natural site was due mainly to higher salinity values (> 187%) from tidal influence, and the community/habitat was apparently not as conducive to bird recolonization, since this marsh had the lowest number of bird species (figures 6, 7). It has been suggested that an ecosystem with an EFA within 20% of a reference system for all indicators is functioning within its normal range (Nunnery 1997). Thus, the Suq Al-Shuyukh marsh is closest to matching wetland functions in the remaining natural Al-Hawizeh. Clearly, the Al-Hammar marsh is not as similar to the natural site in functioning as Suq Al-Shuyukh, but there is no easy way to assess whether this was historically the case or whether it simply has not fully recovered.

These metrics, when scaled against historical values, indicate that none of the remaining marshes were fully functioning when compared with earlier measured ecosystem levels (figure 7). It should be noted that the historic values we used in our scaling were the weighted averages of the highest rates from a number of marsh studies done before drainage, but we have no way of assessing the exact locations of earlier studies in the marshes. Indices of production functions (plant production), decomposition/redox status (oxygen status), and biogeochemistry functions (salinity) in all current marshes were close to historic values, except that salinity was higher in Al-Hammar as a result of recent tidal influences. Further measurements of salinity in the lower Al-Hammar indicated that current values there were close to the historic averages of 1.7 ppt that were measured when the tides were still allowed to flow, before the destruction of the marsh under Saddam Hussein's regime (Hussain 1992). This indicates that this marsh has always been more saline than other marsh areas because of tidal influences. However, the number of bird species (community/habitat function) and transparency depth (hydrologic function) were all much less (50% to 60%) in the current marshes than they were historically. This is not unexpected, given the recent reflooding of wetlands that had been drained for over a decade.

Integrating the functional space for each wetland (scaled total area covered for five functions within each polygon shown on figure 7) gives us a rudimentary way to assess the overall recovery of each wetland ecosystem as weighed against historical values. The natural Al-Hawizeh EFA is 60% of historic values, while the reflooded Suq Al-Shuyukh and Al-Hammar reach 54% and 49% of historic levels after only two years of reflooding. These findings suggest several interesting possibilities. First, the natural Al-Hawizeh may itself be more damaged than has been recognized and functioning only at two-thirds of historic capacity, or it may not be a proper reference marsh to use for comparisons because of differences in soil conditions and water sources (Richardson et al. 2005). Second, the reflooded marshes are on the road to restoration but, as expected, have not reached full wetland functioning in less than two full growing seasons. Of course, a better selection of indicators for some functions (e.g., decomposition rate studies that are now under way) may provide a better assessment of restoration success in the future. The indications of a rise in salinity over historic conditions and a decrease in depth of water clarity in the reflooded marshes are matters of some concern. We do not know whether these salinity and clarity trends will continue, but if they do, they may affect overall restoration. However, the fast recovery of plant production, overall good water quality, and the rapid increases in most wetland functions indicate that recovery of ecosystem function is well under way.

Water availability in the future

Approximately 70% of the water entering Iraq comes from river flow controlled by Turkey, Iran, and Syria (Partow 2001). Annual rainfall only averages around 10 cm in southern Iraq, while evapotranspiration rates can reach nearly 200 cm (Buringh 1960). Groundwater sources are highly saline and not useful for drinking or irrigation without expensive treatment (Buringh 1960). A series of major transboundary water issues include the completion of the massive Southeastern Anatolia Irrigation Project (GAP) in Turkey, with 22 dams supplying irrigation water to 1.7 million hectares (ha) of agricultural land, and the Tabqa Dam project in Syria, supplying water to 345,000 ha of irrigated land (Lorenz and Erickson 1999). In addition, the dike being built by Iran to cut off the Iranian water supply to the Iraqi portion of the Al-Hawizeh is nearing completion (Richardson et al. 2005). The water from the Iranian project reportedly will be sold to Kuwait, which suffers severe freshwater supply problems. The Atatürk Dam, built in Turkey as part of GAP in 1998, can store more than the 30.7 billion cubic meters (m^3) of water that flows annually through the Euphrates from Turkey into Iraq; this dam alone could almost dry up the Euphrates (Partow 2001).

Projected future demands for water for agriculture and other human uses are enormous, with estimates of Iraq's water needs close to 95 billion m^3 by 2020; however, only 48 billion m^3 are estimated to be available after Turkey and Syria complete their dams (Farhan 2005). Farhan (2005) also estimates that to restore 10,000 km^2 of marshes will require from 20 billion to 30 billion m^3 of water, nearly 50% of Iraq's available water after the completion of the water projects and dams in Turkey and Syria (Partow 2001). It is clear from these estimates that there will not be enough water to meet the projected needs of Iraq's population and agriculture; thus, the marshes will be in direct competition for water. This will be especially true in drought years. However, some of the used agricultural water may be adequate for use in the marshes, but that has not been studied in terms of elevated salinity and long-term nutrient and pesticide effects.

Given the competition for water among cities, agriculture, and marshes, serious shortages will exist, especially in dry years. Because the amount of water available for the marshes may be severely restricted in some years, water should be directed only into those former marshes with the most potential for maintenance of natural existing areas (e.g., Al-Hawizeh) or for restoration of functional wetland ecosystems (e.g., Suq Al-Shuyukh). Other sites need to be chosen after completion of an ecological survey and soils assessment to prevent the release of precious water into areas with lower restoration potential. Another problem will arise when areas that have been partially restored after water has been released into them have their water supplies cut off during drought-year shortages. This will result in further destruction of soil structure and overall loss of biota. To prevent this, a set minimum yearly water allocation should be made to the most viable former marsh areas. A working example of this approach is the minimum water allocation designated for the marshes in the Everglades to maintain ecosystem functions under the recent Everglades restoration plan (Sklar et al. 2005). In Iraq, the Center for Restoration of Iraqi Marshes will need to work closely with all the ministries, especially the Ministry of Water Resources and the Ministry of Agriculture, to maintain future water supplies for the marshes. The wild card in this plan is the Ministry of Oil, which has not actively participated in the marsh restoration program; vast quantities of oil are reported to exist under former marsh areas in southern Iraq.

Will Marsh Arabs return?

The question that is always asked is whether the Marsh Arabs are returning to the marshes that have now been reflooded (figures 1c, 3e, 3f). A recent survey done by USAID indicates that not all of the Marsh Arabs want to return to live full-time in the marshes (DAI 2004). The idyllic marsh life that has so often been portrayed in the Western press is in reality a life of poverty, disease, tribal wars, and, often, early death. Nonetheless, some of the former Marsh Arabs do choose to return to the marshes. On several trips we noted an increasing number of families returning to Suq Al-Shuyukh and Al-Hammar. When asked why they returned, they simply stated that they had no other place to go and that the marsh provides some protection and food. However, the number of people who have returned is probably under 10,000, and recent estimates indicate that fewer than 10% of the remaining Marsh Arabs may return because of the marshes' poor fishing and lack of clean drinking water, schools, and health clinics. Moreover, many of the former Marsh Arabs are now successfully farming on the edge of the marshes. For the first time in their lives, many are making a meager living by farming wheat, rice, and barley (DAI 2004). When asked if they want the marshes back for fishing and hunting, they answer yes, but not if their farms and homes are flooded (DAI 2004). Thus the future of the Marsh Arab culture is in jeopardy. While some will return to their ancient life of buffalo herding, fishing, and hunting, many will not—especially the young. Those who do return will need to receive a long-term commitment to sufficient water to sustain the restored marshes and access to life's basic amenities. When Marsh Arabs have specific preferences for the areas they want to resettle, these preferences should be among the criteria for selecting marsh areas to be restored; however, these areas must also meet the ecological conditions conducive for reestablishing wetland functions if both ecosystem restoration and cultural reestablishment are to be successful.

Conclusions

The restoration of southern Iraq's Mesopotamian marshes is now a giant ecosystem-level experiment. Uncontrolled release of water in many areas is resulting in the return of native plants and animals, including rare and endangered species of birds, mammals, and plants. The rate of restoration is remarkable, considering that reflooding occurred only about two years ago.

Although recovery is not so pronounced in some areas because of elevated salinity and toxicity, many locations seem to be functioning at levels close to those of the natural Al-Hawizeh marsh, and even at historic levels in some areas. These major questions remain to be answered:

- Will water supplies needed for marsh restoration be available in the future, given the competition for water from Turkey, Syria, and Iran, as well as competing water uses within Iraq itself?
- Can the Marsh Arab culture ever be reestablished in any significant way in the restored marshes?
- Can the landscape connectivity of the marshes be reestablished to maintain species diversity?

What is clear is that water supply alone will not be sufficient to fully restore all the marshes, and thus a goal of management should be to establish a series of marshes with connected habitats (Theobald and Hobbs 2001) of sufficient size to maintain a functioning wetland landscape. Iraq must also use water more efficiently and cut waste if the country is to have enough water to meet its future needs. For example, the continued use of the ancient method of flooding vast agricultural fields from open ditches, coupled with extremely high evapotranspiration rates, results in massive losses of water to the atmosphere and increased soil salinity problems (Buringh 1960). Modern drip irrigation approaches used throughout other parts of the Middle East need to be employed to preserve Iraq's dwindling water supply.

Monitoring is continuing under USAID and international funding to assess the recovery, and additional efforts are now being focused on measuring plant and fish production, changes in water quality, and specific populations of rare and endangered species. Unfortunately, no research is under way to assess how agriculture and the marshes can share scarce water supplies, to identify toxic problem areas, to study the problems of insecticide use by local fishermen, or to conduct a complete survey of the marshes to determine optimum restoration sites, because of limited funding and increased violence in the area. However, the long-term future of the former Garden of Eden really depends on the willingness of Iraq's government to commit sufficient water for marsh restoration and to designate specific areas as national wetland reserves. Political pressure from the international community to maintain water supplies flowing into Iraq will also be critical to the restoration of the marshes.

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