North African wetland lakes: characterization of nine sites included in the CASSARINA Project

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Abstract

Exploitation of land and water resources has increased rapidly in North Africa during the 20th century, paralleling regional population growth. As part of the CASSARINA Project (see Flower, 2001), the environmental status of nine wetland lakes in Morocco, Tunisia, and Egypt was evaluated. All are conservationally important habitats and several are Ramsar Sites (internationally recognized bird reserves) and several support significant fisheries. All are shallow (<2 m in depth) but vary greatly in area.

Where available, documentary information on relevant 20th century changes is given. Survey transects for aquatic vegetation were established and used to provide baseline ecological information on the aquatic plant communities during 1997–1999. Unusually, one site (Tunisian Megene Chitane) supported acidophilous vegetation (some taxa being nationally rare). Aquatic macrophytes declined catastrophically at two sites during the 1990s. Merja Bokka was drained in 1998 and, at Garaet El Ichkeul, fringing *Phragmites* and *Scirpus* spp. were lost, mainly as a result of salinity changes. Elsewhere, fringing macrophytes remain (extensively so in the Nile Delta lakes) common, despite major land reclamation and water quality problems, or are degraded by grazing (Merja Zerga). Marginal vegetation during 1997/98 changed markedly at Megene Chitane due to water level lowering.

Documentary records indicated that throughout the 20th century, reclamation and hydrologic modifications, mainly for agricultural purposes, affected all nine sites. The loss of lake area by reclamation is substantial for the Nile Delta lakes (Edku, Burullus and Manzala). For the western sites,

some data indicate increasing salinity in the most recent decade but the Delta lakes have become generally fresher during the 20th century, as supply of Nile water for irrigation increased.

Despite intense human disturbance, many of the remaining CASSARINA sites still support regions of high aquatic diversity. Spatial scale monitoring of the larger sites for seasonal and inter-annual changes in open water area and in aquatic plant abundances is a key requirement for integrated environmental change assessment in the 21st century.

Introduction

Wetlands and shallow lakes are a diminishing global resource (Finlayson & Moser, 1992). In North Africa, 20th century land-use changes have had a particularly strong and damaging impact on many biologically important natural wetland lakes (Finlayson et al., 1992; Green et al., 2001). The nature and pace of wetland lake loss and degradation in this region during the 20th century are however generally poorly known. In order to assess recent environmental change histories and the current status of remaining North African wetland lakes, the CASSARINA Project was begun in 1997. The specific aims and structure of CASSARINA are described in Flower (2001) and the project focuses on modern environmental survey and on recent palaeoecology of nine sites selected in Morocco, Tunisia and Egypt. Here we describe the current environmental status of each site by reviewing relevant past work and describing the principle site attributes by placing special emphasis on littoral macrophytes and on documentary site records.

Wetland lakes can be defined as any enclosed body of water, fresh or saline, that is 6 m or less in depth (Davis, 1994), and all nine CASSARINA sites fall within this definition. They comprise a group of strongly contrasted types thought broadly to represent the range of wetland lakes occurring in the North African region today. All are near the coast and six have direct connections to the sea, seven are designated birds reserves and six support significant fisheries. All nine sites, therefore, can be considered to possess high value for some aspect of biodiversity. In addition, they all share one other common feature, they are all affected by human activity.

Previous research on Cassarina Sites

In common with many European regions, some CASSARINA lakes have been relatively well studied but others have not. The North African sites are particularly sensitive to disturbance because a dry climate and intensive land-use during the 20th century have combined synergistically to change hydrological regimes markedly. In Morocco, lake studies have focused extensively on the merjas Sidi Bou Rhaba (SBR) and Zerga, mainly because of their value as bird reserves. SBR has added biodiversity value since it is surrounded by relatively undisturbed woodland (Atbib, 1979–1980). It supports a high diversity of birds (Thevenot, 1976), invertebrates (Ramdani, 1980, 1981, 1982, 1986, 1988; Morgan & Boy, 1980, 1982) and macrophytes (Gayral, 1954; Elkhiati, 1987, 1995). Additionally, the Holocene vegetational history of the site is known (Reille, 1969). SBR was classified as a Ramsar site in 1971 and it was made a National Nature Reserve in 1975. Zerga (90 km North of SBR) was also designated a Ramsar site in 1971 and it became a permanent biological reserve in 1978. Its hydrology and vegetation have been studied since the 1970s (Beaubrun, 1976; Lacoste, 1984). More recently, the site was included in the MedWet2 programme on Mediterranean wetlands of importance as bird reserves (Dakki et al., 1997; Bayed et al., 1997). The third Moroccan site Merja Bokka has only been previously investigated for zooplankton (Ramdani, 1988) but was known locally as a high value site for water birds.

In Tunisia, Garaet El Ichkeul is perhaps the most thoroughly studied inland lake. Its water quality and large migrant bird populations were the focus of much research during 1930s-1990s (Lavauden, 1937; Chaumont, 1956; Kellal, 1979; Fay, 1980; Scott, 1980; Lemoalle, 1983; Morgan & Boy, 1980, 1982; Ayache, 1988; Stevenson et al., 1991; Hollis, 1986, 1992; Tamisier et al., 1987, 1992). The fish (Heldt, 1948; Farrugio, 1975; Losse et al., 1992; Kraïem et al., 2001) and palaeoecology of this site are also relatively well studied (Stevenson et al., 1986; Stevenson & Battarbee, 1991). The other two Tunisian sites are however virtually unstudied although Korba Lake is well known for birds (Kraïem & Ben Hamza,

2000) and the palaeoecological value of the small acid valley mire and lake (Megene Chitane) near Jbel Chitane was noted by Ben Tiba (1980).

In the Egyptian Nile Delta the three sites (Lakes Edku, Burullus and Manzala) have been investigated in some detail during recent decades and, in comparison with the other CASSARINA sites, a wealth of information is available. The broad research foci were birds (e.g. Goodman & Meininger, 1989), fisheries (Khalil & Salib, 1986) and vegetation (El Hadidi, 1976; Khedr & Lovett-Doust, 2000). Publications mainly concerned human pressures on these lakes causing loss of area and declining water quality (Khalil & Salib, 1986; Abou-Arab et al., 1995) or sediment quality (Saad et al., 1985). Meininger and Mullie (1981) recognized the threat of these changes to the large over-wintering bird populations. Aspects of the chemistry and biology of the Delta lakes have been reported in a group of papers published from Alexandria University (El-Hawary, 1960; Samaan; 1974; El-Sherif, 1993) and elsewhere (Shaheen & Yousef, 1980; Banoub, 1979). The recent geological evolution of lakes in this region was established in the late 1980s/90s (Stanley & Warne, 1994 and related papers).

Lake morphometries, related characteristics and documentary records

All nine CASSARINA lakes are shallow (< 2.5 m deep) yet they vary greatly in area, from < 1 to ~1000 km2 (Table 1). Strictly, those that have direct channel contact with the sea (Zerga, Ichkeul, Korba and the Delta lakes) are lagoons. Mean annual rainfall declines from west (~500 mm) to east (~100 mm) and prevailing winds are westerly for Morocco (Le Coz, 1964; Ramdani, 1982) but in Egypt easterly or southeasterly winds are common from March to September (Samaan, 1974; El-Sherif, 1993).

Site descriptions

The regional locations of the nine sites are given in Flower et al. (2001) and individual site maps (Figures 1–4) show locations of vegetation transects and sediment core positions (see Ramdani et al., 2001b). Site location, morphometric characteristics and other details are given in Table 1.

Morocco

Merja Sidi Bou Rhaba (Figure 1) is a shallow valley lake and during the spring periods (1997/98) was 2 m deep in the central region (Table 1). There are no surface inflows or outflows and water level can drop by ca. 1 m by late summer so that the southern portion of the lake usually dries out (it was continuously dry for several years during the early 1980s drought). The southern part is locally colonized by Chenopods (e.g., *Chenopodium chenopodioides*). Around the lake *Eucalyptus, Juniperus phoenicea, Pistacia lentiscus, Retama monosperma, Populus alba, Phillyrea angustifolia, Chamaerops humilis, Tamarix gallica*, and *Olea europaea* woodland is relatively undisturbed. The lake water is generally turbid green and overlies soft grey-brown sediment. A large sand dune ridge separates the lake from the Atlantic, some 1000 m to the west. There is no communication with the River Sebou that flows into the Atlantic immediately to the North of the lake but the lake may have been a former channel of this river.

Merja Zerga is a large lagoon, in communication with the Atlantic via the ‘gullet’ at its north west corner (Figure 1b), the whole basin is tidal to some extent. Water depth is generally <50 cm (Table 1) and varies depending on tidal cycle and location but ~2 m depths occur in some drainage channels at high tide. Tidal influence is much reduced in the southern part of the merja where level fluctuations are <40 cm. Sheep/goat grazing on the foreshore margins of the lagoon is encouraged and remnant *Phragmites* persist. Fish traps are common and bivalve molluscs are harvested. Increasingly intensive agriculture (cereals and fruits) is practised east of the lagoon. Subsistence housing is proliferating around the lagoon and ground water is increasingly exploited for irrigation (Hollis, 1992). In addition to agriculture, surrounding land is also used for *Eucalyptus* plantations (Figure 1). Aerial photographs (1950, 1960) indicate that the marginal reed beds were at their largest extent in the latter period. Before 1953 only seawater was present in the southern part (Le Coz, 1964). Old maps (Le Coz, 1964; Bidet et al., 1977) show that the only

Table 1. Some site characteristics for the nine CASSARINA wetland lakes, including locations of the vegetation transects (GPS start points and compass bearings) established in this project. Two transects were established at Ichkeul, T4 and T14. Morphometric data refer to the period of sampling (1997–1998). *Data in parentheses are for Merja Khala, a sub-basin of Merja Zerga. SBR indicates Merja Sidi Bou Rhaba

	SBR	Zerga (Kahla)*	Bokka	Chitane	Ichkeul	Korba	Edku	Burullus	Manzala
Site co-ordinates	34°12′–15′ N 06°42′–45′E	34°17′ N 06°13′ E	34°25′ N 06°12′ E	37°11′ N 09° 10′ E	37°02′ N 09° 48′ E	36°46′ N 11° 00′ E	31°15′ N 30°15′ E	31°21′ N 30°30′–31°10′ E	31°30′ N 31°45′–32°15′ E
Area (km^2)	1.7	20–22 (3)	0.05	0.025	89	0.32	126	570	1200
Depth range (cm)	100–200	3–80 (5–40)	20–90 (pre-1998)	40–100	10–80	15–85	50–200	50–160	70–250
Max T°C air	30.5	31.8	30.5	39.5	44	40	44	44	44
Min T°C air	11.6	13	11.6	11	11	11	9.1	10.7	8.6
Secchi depth (cm)	5–50	5–25	4–20	30–80	5–95	5–60	21–36	30.46	32–45
Start transect line	34·24274 N 06·67193 W	34·82883 N (34·87233 N) 06·29490 W (06·25484 W)*	34·37241 N 06·28715 W	37·15350 N 09·09760 E	T4: 37·11268 N 9·71629 E T14: 37·15232 N 9·56349 E	36·63476 N 10·90157 E	31·26574 N 30·21107 E	31·26182 N 30·38496 E	31·32003 N 30·34853 E
Compass	345° NW	20° NW (221° W)	235° NW	95° E	T4: 180° T14: 60°	137° NE	18° N	10° N	84° NE
Salinity (‰)	4.5–8.1	8.2–21.5 SE part (9.5–32)	1.3–2.5	0.4–1.2	16.6–34	20–79	0.7–1.5	1–2.9	0.5–1.6
Dominant wind	SW	SW	SW	NE	NE	NW, W	NW, NE	NW, NE	NW, SW
Main Annual Rainfall (mm)	596	526	596	500	578	450	196.7	196.7	112.2

freshwater sources then were springs, local runoff and the Drader River in the north-eastern part of the lake. At this time, *Arthrocnemum macrostachyum* dominated the southern marginal vegetation (Lacoste, 1984). However, in 1953 the Nador canal was built, as part of a drainage scheme for the Rharb region, and fresh water runoff was introduced to the southern part of the Merja. This promoted local fringing macrophytes such as *Juncus acutus* and *Phragmites*. These communities however have been severely depleted in recent years by overgrazing and harvesting. At several times in the past (1928, 1951, 1976, 1986) the lake level was raised abnormally by blocking of the outflow channel by sand bars (Ramdani & Elkhiati, 2000).

Merja Bokka (Figure 1) was formerly a substantial lake that was already much reduced in size at the start of CASSARINA (1997). It was then still ~250 m in diameter but very shallow (Table 1). Before the 1980s, this permanent water body supported extensive emergent macrophyte communities. Aerial photographs showed several small low islands which by the mid 1990s were covered with *Panicum repens* and *Typha angustifolia*. Several former higher lake-level shorelines occurred around the lake indicating that past levels were maintained at 1 and 2 m depths. The inflow stream became redundant in the mid 1990s as water was abstracted for agriculture. Formerly common *Phragmites* was reduced by burning and drainage in the 1980s. In 1997 the lake possessed a few introduced small carp and many amphibians, especially the newt, *Pleurodeles waltli*. The site lies on ancient deposits of the Oued Tiflet and old maps (Ramdani & Elkhiati, 2000) indicate that Bokka was an enlarged flood channel of the Sebou River in the 19th century. In the mid 1930s extensive planting of *Eucalyptus* began following French colonization (1928) and this was extended in ca. 1960. French development also included local drainage schemes so that before the 1930s the Bokka region was an extensive wetland, occasionally inundated by Sebou River floods. Later, the wetland was partly reclaimed and land around the lake was cultivated. Since the 1970s, flooding was eliminated and the lake increasingly has been isolated from inflowing water. In the mid 1990s, ploughing and cereal production intensified and encroached onto the fore-shore. Water abstraction and drainage increased during the 1990s and to such an extent that in late 1998, the whole lake area was under agricultural production with wheat/sunflower crops. In 1999, only a vestigial *Juncus/Scirpus/Typha* marginal zone marked the former lake.

Tunisia

Megene Chitane is a small, usually clear, soft water lake located on the north slope of Jbel Chitane at 150 m altitude, overlooking the Mediterranean Sea to the north (Figure 1). The site is protected and was declared a nature reserve in 1993. The outflow is ephemeral and is located in the NW corner. In December 1997 it was perched about 60 cm above the lake level. Maximum water depth (April 1997) was 97 cm. The catchment includes cork oak with fairly undisturbed scrub understorey. A perimeter fence some 50–100 m from the lake shores protects the catchment within the vicinity of the lake. Up-slope from the lake, subsistence farming is practised on a small area of the valley mire. A small aquifer supplies two small freshwater springs that feeds the upper mire bog and eventually the lake. Water flowing through the mire is currently being exploited for crop irrigation. The sandstone aquifer and the peat bog are acid and this confers acidity to the lake. The lake sediment was (in 1997/98) covered everywhere with desiccation fissures marking the earlier loss of surface water (in 1995/96).Water depth was low in April 1997 and the exposed sandy former littoral zone was covered with terrestrial vegetation (*Cotula coronopifolia* and some grasses). Forestry authorities introduced fish but these were lost during the mid 1990s desiccation period. Loss of standing water probably resulted from over-exploitation of the lake's natural acid spring water supply. Nevertheless, the lake currently supports many *Nymphaea alba, Juncus heterophyllus* and *Isoetes velata*.

Garaet El Ichkeul is a large shallow brackish lake (Figure 2) that has experienced major disturbance in recent decades (Stevenson & Battarbee, 1991). Although it is surrounded by productive agriculture (mainly cereal crops in the Mateur region), the main changes stem from 20th century hydrological modifications of the five main inflowing rivers. Following canalization, all but one of these inflows has been barraged since 1984 so that freshwater inputs are now much reduced. Whereas in the past, water usually flowed out from the lake to the sea, seawater now tends to flow into the lake during dry

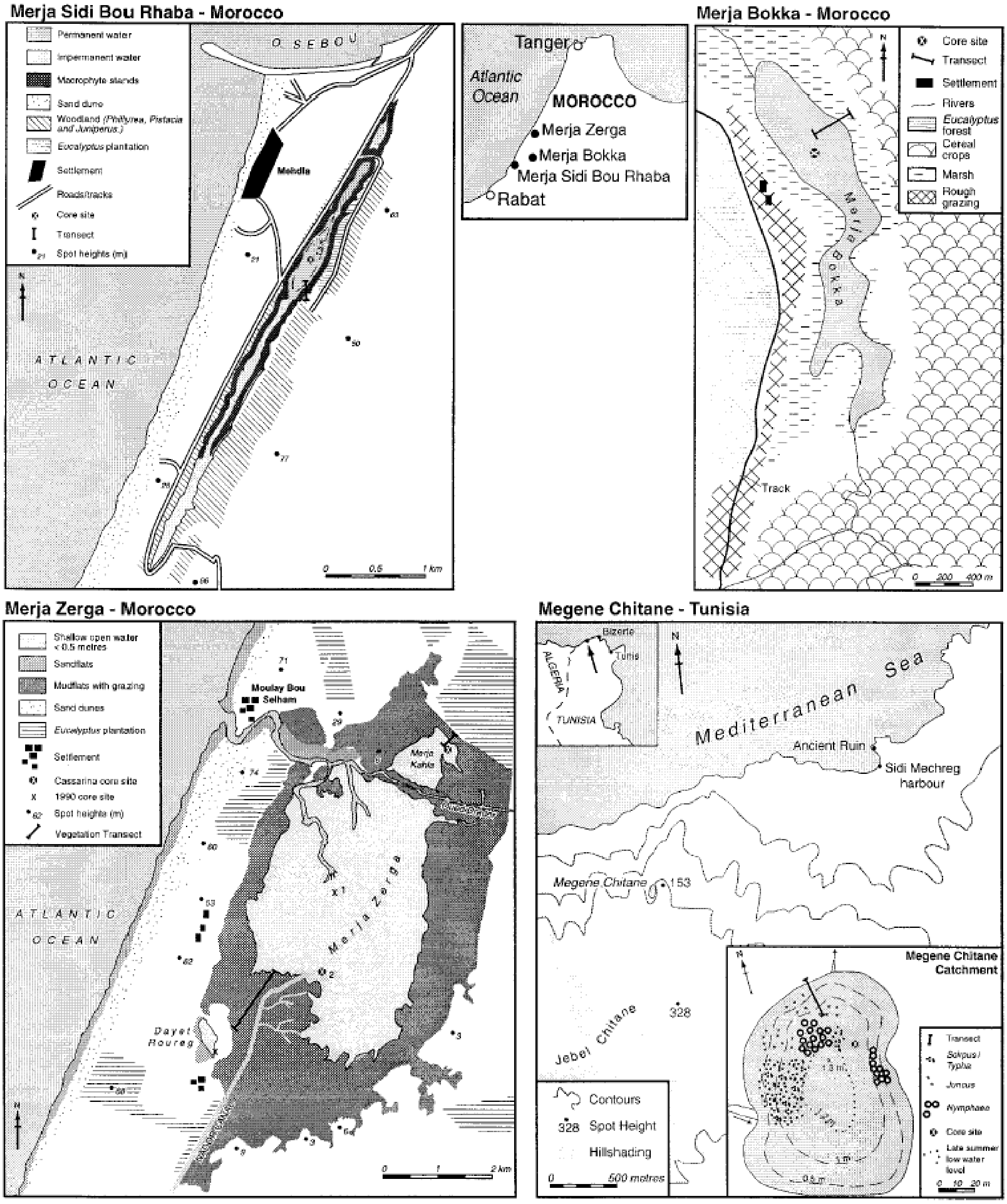
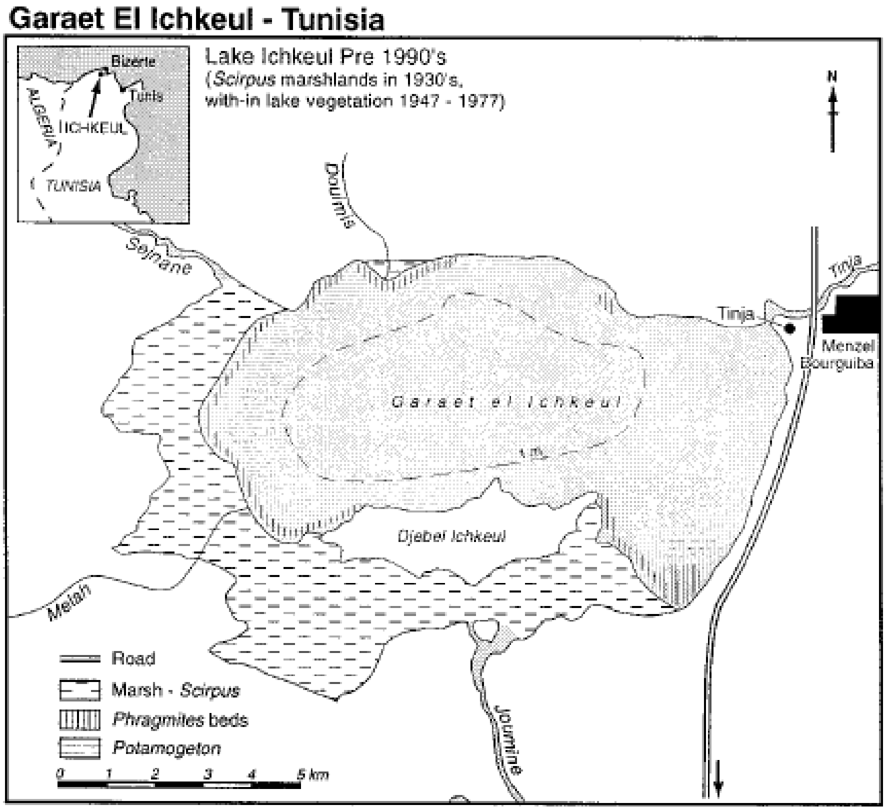


Figure 1. Site maps and sampling points for the three Moroccan CASSARINA sites, Merjas Sidi Bou Rhaba, Zerga and Bokka and the Tunisian CASSARINA site, Megene Chitane. The locations of the vegetation transects and sediment core locations at each site are noted.

periods. The lake bed is 1.5 m below sea level, which is the lake depth in summer. In winter, lake level increases are now attenuated and the former marsh zone is only partly inundated. Since 1986, sluice gates on the Tinja River outflow have control over seawater inflow but there are conflicts between fisheries and biodiversity interests. In recent years, the salinity of Ichkeul has increased so that hypersalinity persisted in the mid 1990s (Kraïem & Ben Hamza, 2000). The Ichkeul region was designated a Biosphere Reserve in 1977 and a World Heritage site in 1979. The International Park was declared in 1980, and the lake is listed as a Ramsar site (Hughes et al., 1996). The marshland and the lake used to receive some 200 000 over-wintering and migratory birds annually, mainly ducks, coots, grebes cormorants, spoonbills, storks, herons, and waders. Especially the geese have declined in the 1990s mainly because of marshland loss.

Korba Lake occupies a long narrow shallow channel on the east coast of the Cap Bon peninsular (Figure 3). A partially vegetated low sand dune separates it from the Mediterranean, approximately 100 m distant. Water quality is affected at the south part by pollution from Korba town and also by sea water penetration. At two points, the sand dune is breached forming temporary connections with the Mediterranean. Seasonal fresh water inflows to the north end of the lake from nearby streams (Chiba and Boulidin wadis) occur but water abstraction for agriculture is intense. In recent years, salt water has encroached into the freshwater-table in the Korba region (C. Ben Hamza, pers. commun.). On the lake's west side, soil is irrigated for crops in summer months and is separated from the lake by a *Salicornia* salt marsh. At the lake centre, depth varies from 30 to 60 cm (Table 1) and the shallower north part consists of hard packed grey clays, probably ancient and of marine origin. A large part of the lake bed is covered by a dense mat of green filamentous algae with chironomid larvae. Since the 1920s, the seaward sand dunes have expanded and aerial photography shows that since 1987 Sebkhat Lobna has disappeared as a result of the extension of Korba town and the damming of the Lobna River (Kraïem & Ben Hamza, 2000). Korba Lake has international ornithological importance and supports over 45 species of migratory water birds, mainly ducks, flamingoes, gulls, pintail, ducks, avocets and herons (Tamisier et al., 1992; Kraïem & Ben Hamza, 2000).



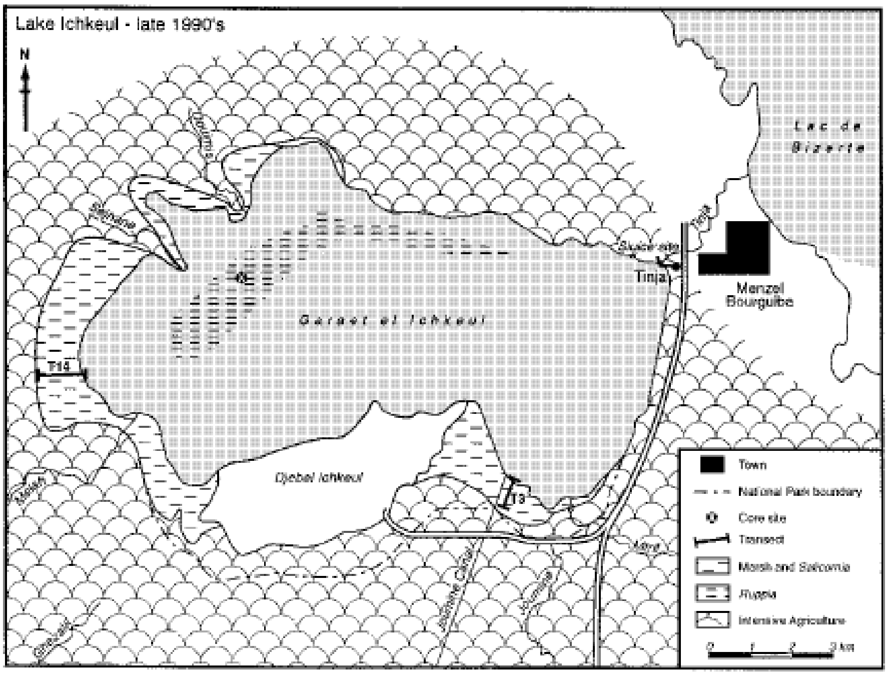


Figure 2. The Tunisian CASSARINA site Garaet El Ichkeul. *Upper*: indicates the past nature of the site, with extensive *Scirpus* marsh lands in 1930 (after Lavauden, 1937) and *Potamogeton* dominated with-in lake vegetation (1947–1988, Stevenson 1991, Stevenson and Battarbee 1991). *Lower*: the status of Ichkeul in the late 1990s, according to CASSARINA surveys, note the loss of fringing *Phragmites* and replacement of *Potamogeton* with *Ruppia* and *Scirpus* with *Salicornia(=Arthrocnemum)*. The CASSARINA core locations and vegetation transect lines are also shown.

Egypt

The shallow coastal lakes on the Nile Delta have been subjected to major disturbance since ancient times (Butzer, 1976). The hydrological regime of all these lakes results from a balance of freshwater runoff from the agricultural regions in the south and seawater input from the north. Where undisturbed by land reclamation and development, the lake margins are extensively vegetated, mainly by *Phragmites* and *Typha*. These plants are also frequent on the islands and everywhere water hyacinth (*Eichhornia crassipes*) is proliferating. Productive agriculture around the lakes, date palm and sugar cane plantations, cereals and leguminous crops, has been encouraged by the increased supply of fresh Nile water for irrigation in recent decades. The water quality of all the lakes is locally affected by sewage and agro-chemicals supplied mainly from the southern agricultural drainage regions. Many Palearctic bird species migrate via the Delta lakes in internationally significant numbers (Goodman & Meininger, 1989). These weakly brackish lakes all support fisheries.

Lake Edku is surrounded by a productive agriculture to the south, by ongoing land reclamation activities to the east side and by housing and industry to the west side where much reclamation has occurred since the 19th century (Figure 3). The northern border of the lake is a sand ridge that separates the lake from the sea and supports date palm groves, subsistence agriculture and several villages. Irrigation here is by direct pumping of lake water. Immediately to the north-west, the urban sprawl of Alexandria begins with the industrial installations at Abu Qir (the WEPCO and GASCO oil and gas refineries, oil powered electricity-generating plant, a paper processing plant and the fertilizer manufacturing utility) mostly established in the 1960s/70s. A short unsluiced channel just east of Abu Qir connects the lake to the sea.

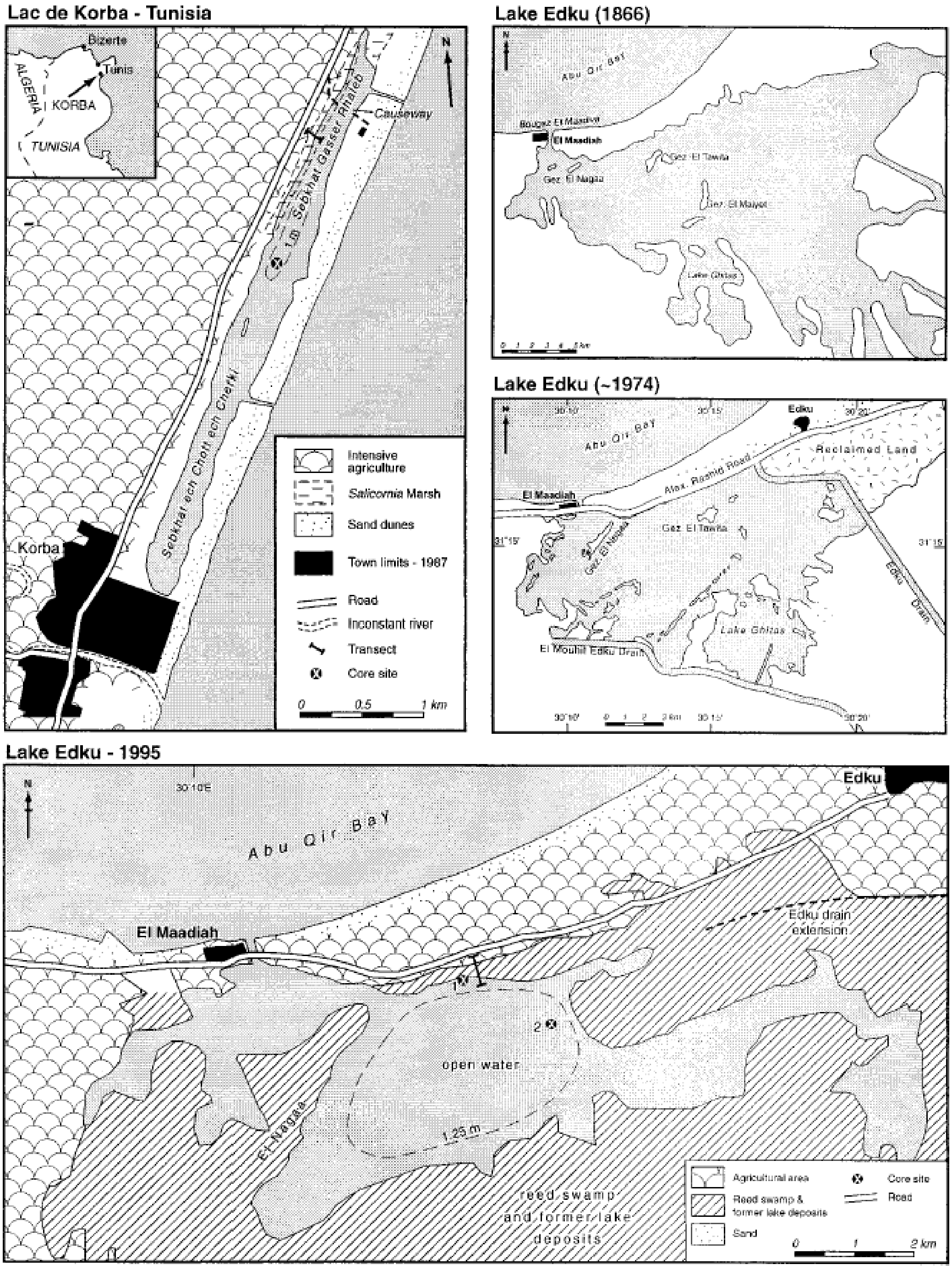


Figure 3. The Tunisian CASSARINA site Lac de Korba on the east coast of the Cap Bon peninsular, note that in the 1960s the town limits were west of the coast road. The three maps of Egyptian Edku Lake on the Nile Delta indicate lake status on three periods, 1866, early 1970s (after Samman, 1974) and in ~1995. Note the scales and the diminishing area of Edku with time. CASSARINA core sites and vegetation transects are noted on the contemporary maps.

Table 2. Summary of documentary information about 20th century landuse and lake changes that have occurred at the nine CASSARINA wetland sites. A variety of information sources (see text) have been consulted to prepare this summary. The three Delta sites, Edku, Burullus and Manzala lakes have been treated together here since they are affected by broadly similar hydrological/agricultural changes in the past 100 years. SBR = Sidi Bon Rhaba

	SBR	Zerga	Bokka	Chitane	Ichkeul	Korba	Nile Delta
1960s–1990s	Traditional fishing reintroduction of black bass and introduction of carp 1950s; pesticides HCH, DDE, DDT used 1964; classified in international wetlands list & made a National Nature Reserve in 1975; visitors car park built in 1976; tourism and birds watching increasing museum and training center on eastern shore in 1988; migratory water bird protection begins. Grazing and cutting of rushes controlled; Ramsar site in 1971	Drainage & irrigation, much agro-chemical usage for crop improvement; pesticides, fertilizers, manure, peat used in seedbeds; numerous green houses installed (and increasing post-2000); ground water pumping from 1960s; new techniques of irrigation introduced; 62 boats fishing in the merja post 1990; Ramsar site in 1971; Nature Reserve in 1978 with protection of migratory birds; *Salicornia* marsh expanding; ducks, geese and swan numbers decling; birds watching tourism activities increasing	Intensive drainage - irrigation; flooding eliminated; Sebou water reduced post -1963; large-scale centralized farming declines (1965–1970); large-scale farming declined (1965); HCH and fertilizers, DDE, agro-chemicals use increasing; lake dried up 1998; western region turned to *Eucalyptus* forestry; *Helianthus annuus* (sunflowers) planted on lakebed in late 1998.	Insecticide(DDT) used in 1957; carp and *Nymphaea alba* in c. 1960 forest fire 1966; clearance of mire bog for cultivation in 1960's; crops and fertilizers used post c. 1980; water abstraction of inflows in 1990s; protection fencing of the lake in 1990s.	Mechanization of agriculture; pumping groundwater since 1960s; drainage of marshes after canalization: irrigational improvements extended in 1981; Oued Melah canalized in 1960s; fishing activities increase; drainage and dams building first inflow barrage 1983 (Sedjnane in 1993); pesticides and fertilizers used; intensive summer pumping of freshwater; decrease of water birds numbers post 1990; reduction of marsh area from 10000 to <8500 ha; *Scirpus* marsh and *Phragmites* lost in late 1980s; Tindja otflow sluiced in 1984.	Agriculture: fertilizers and pesticides used; extension of Korba town, tourism and industry expand (1980–2000); south part polluted; groundwater exploitation for irrigation in agriculture area west of lake; urban regional development plans begun	Delta lakes began pesticide usage in 1950s, lindane, heptachlor, chlordane, toxaphene and DDT increasingly used (toxaphene stopped after 1969, DDT stopped after 1981); synthetic pyrethroids since 1970s; DFB group (Dimilin, Iki) since 1975; Aswan High Dam constructed in 1964 completed 1968; land reclamation continues; pollution with no wastewater treatment; construction of levees; marsh area reduced in parts; >20% area loss of lake areas; expansion of reeds in open water area of Manzala; pollution discharges increasing (sewage from Bahr El Baqar Drain); Peace canal around Manzala completed in mid 1990s; some fishery declines
1920s–1960s	Introduction of black bass and *Gambusia* (1940s); grazing and cutting of rushes harvesting uncontrolled; agriculture intensified beyond the lake boundaries	Marginal rushes exploitation (Artisan mats), agriculture and grazing; *Salicornia*/ *Juncus* marsh in south part, fishing regulations imposed Decree of June 1931 (shellfish and Pisces).	Traditional irrigation.; surrounding agricultural improvements; centralized farming practices; flood control; changes to drainage system; *Eucalyptus* forestation begins	Catchment fires 1943, 1948, 1957; hunting.	Traditional agriculture and grazing; irrigation improvements; fishing; French agricultural development; agriculture improvements in Plain of Mateur; canalization of Joumine	Traditional agriculture; crop irrigation improvements	Nicotine, mineral oil and metal salts used to control pests (1940s); lake water becomes more fresh; Mohamed Ali barrages again raised and improved in 1937/39; smaller barrages built on the Rosetta branch at Edfina in 1949–1951; Zefta barrage improved in 1949–1953; canals constructed; local *Casuarina* and *Eucalyptus* planting begun in 1920s, reclamation begins.
ca.1900–1920s	*Eucalyptus/ Populus* planted, road constructed isolating the north basin in 1917; agriculturists active; grazing & cutting of rushes; *Phragmites/ Typha/Juncus* abundant	Traditional irrigation O. Drader; cactus (*Opuntia ficus-barbarica*) introduced; marginal rushes exploited; traditional fishing not controlled; rushes extensive on eastern shore	Traditional irrigation, water supply from Sebou, numerous species of fish (barbels & eels); fishing, rush & *Typha* exploitation (artisan mats), bird refuge; shore encampments for exploiting wetland resources.	Planting of *Pinus pinea* (1910); forest near lake; hunting	Traditional agriculture and grazing; widening of Bizerte canal 1895	Traditional agriculture and grazing	Irrigation canals constructed from 1817; Mohamed Ali Barrages built on the two Nile branches and completed late 19th century; new phase of delta irrigation canals began c. 1900; crop productivity increased.

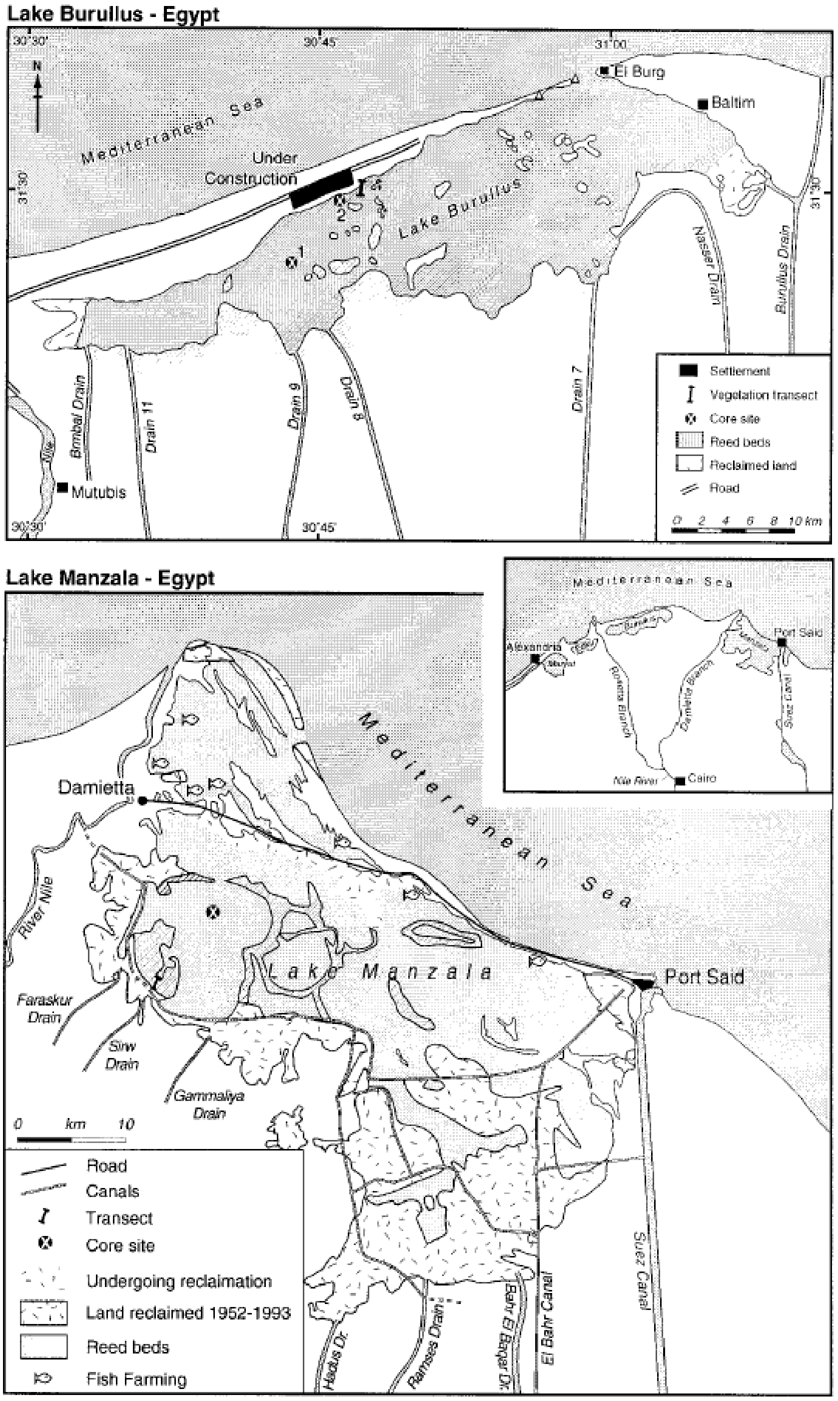


Figure 4. The Egyptian CASSARINA sites Burullus and Manzala lakes on the Nile Delta. *Upper*: Lake Burullus, showing locations of two coring sites and the vegetation transect. Note the construction zone of a new town. *Lower*: Lake Manzala showing the coring site and vegetation transects. Note the reclaimed areas and the complex reed beds (mainly *Phragmites*) extending within the lake.

Burullus Lake (Figure 4) has probably suffered less disturbance than Edku but it is subject to land reclamation, particularly along its southern and western edges. The northern border is a low sand ridge that is currently under development with a town and major road linking Rashida with Damietta (Figure 4). The lake is a Ramsar site and it plays host to large populations of migratory and resident water birds. Valuable cover is provided by extensive beds of *Phragmites* and *Typha* that surround much of the lake and the numerous small islands. *Typha* is more abundant than at Edku but water hyacinth is less so (in 1997–1998). Beyond the reed beds on the northern side of the lake there are extensive patches of submerged *Potamogeton pectinatus* (known as 'waar'); these are important refuges for fish fry. The northern emergent macrophyte belt is often 200–350 m wide. The fishery is productive with Nile perch up to 5 kg being caught in 1999 but bilharzia is increasing locally as declining salinity encourages expansion of vector snails (*Bulinus* and *Biomphalaria*).

Manzala Lake is presently ~1000 km2 in area (Table 1, Figure 4) but has been much reduced by 20th century reclamation. Meininger and Mullie (1981) note that the lake area was formerly 1710 km^2. El Gamil channel in the north-east links the lake to the sea. In the southern part, several canals (e.g., Bahr el Baqr) feed the lake with freshwater (Figure 4). These freshwater drains grossly pollute the lake in the south-eastern sector. The Port Said/ Damiatta road is associated with on-going landfill/drainage activity and much of the north west area is now wholly or partly reclaimed or converted into fish farming lagoons. The south-western region is probably least disturbed with no obvious signs of water pollution and large areas of aquatic plants and major stands of *Phragmites* and *Typha* remain. These stands are cut and harvested and sometimes treated with herbicides and water hyacinth is colonizing large areas of the lake. In the 1980s, the 'Salaam Canal' was constructed (finished in 1996); it runs along the western and southern margins of the lake and conducts Nile water to the Sinai. The newly established southern margin of the lake is the result of this severe disturbance during the 1980s but the effects seem fairly limited regarding within lake vegetation. The reed beds are still extensive in some parts of the lake and help support rich bird life and fisheries. The depth of the water is ~2 m or less, except in the southern region were an over-deepened channel was created by sediment excavation for the canal construction (Figure 4).

Table 3. A summary of known salinity measurements made at several CASSARINA sites since the 1950s. Salinities (T.D.S in g l^{-1}) are taken or transformed from published results. SBr = Merja Sidi Bon Rhaba

	SBR	Bokka	Ichkeul	Edku	Burullus	Manzala
1950s	4.0 (4.6–3.4)[1]		9.3 (28.0–1.8)[4]	1.5 (-)[7]		
1960s			11.8 (18.2–3.5)[5]			4.6 (-)[9]
1970s	4.2 (-)[2]	0.9 (-)[2]	11.1 (29.2–3.9)[5]		3.5 (-)[8]	1.7 (-)[9]
1980s	9.0 (-)[3]		18.7 (32–4.7)[6]			
1990s[10]	6.1 (8.1–4.5)	1.9 (2.5–1.3)	23.5 (31.2–14.5)	0.7 (0.8)	2.4 (1.0)	1.1(0.6)

[1]Gayral, 1954; [2]Ramdani, 1988; [3]Morgan and Boy, 1982; [4]Chaumont, 1956; [5]Conservation Course, 1977 and Muller, 1976 (in Conservation Course, 1977); [6]Lemoalle, 1983; [7]Banoub, 1979; [8]El-Sherif, 1983; [9]Khalil and Salib, 1986; [10]this study (Fathi et al., 2001; Kraïem and Ben Hamza, 2000; Ramdani and Elkhiati, 2000). Note that for the larger lakes (Ichkeul, Edku, Burullus and Manzala) data are selected for lake regions nearest to CASSARINA sampling sites (see Figures 1–4). Parentheses indicate seasonal maximum and minimum values.

Documentary records

Maps, aerial photographs, and various unpublished documents concerning regional historical geography were consulted. Summaries of the principal 20th century known changes at each site are grouped into three periods (Table 2) and are thought to be most appropriate to represent the main phases of development and agricultural improvements. They are: pre-1900 to ca. 1920, when unmechanized subsistence agriculture was generally practised; the 1920s to 1950s, when agriculture improvements occurred as farming became increasingly mechanized and local populations expanded. The 1960s–1990s when intensive farming developed through the use of artificial fertilizers and pesticides and large-scale irrigation and drainage schemes became more significant. Past salinity records are available for some sites and measurements (Table 3). Since the 1950s, the Tunisian and Moroccan sites have tended to become more saline but the Delta lakes became fresher. Ichkeul notably has experienced a salinity crisis, with the annual mean salinity increasing from around 9 in the 1950s to over 20 g salt l^{-1} in the late 1990s. Perhaps most importantly for aquatic life, the winter low salinity phase changed from ca. 2 to over 14 g l^{-1} during this period. All three Delta sites have become less saline since at least the 1950s/60s.

Lake vegetation

At the nine CASSARINA lakes, marginal vegetation was assessed by monitoring survey transects established in 1997. Width of the marginal vegetation belts varied according to site and according to season and linear sampling of plant species by quadrats was used. A linear transect line (two at Ichkeul) was defined for each lake; length and orientation were fixed (using compass, GPS and marker posts) for subsequent precise re-sampling. Sampling was achieved for each season of 1998. Sample points were fixed according to the width of the vegetation belt (2 m for Chitane, 5 m for SBR, 10 m for Bokka and Zerga, 20 m for Korba, 30 m for Edku, Manzala and Burullus, and 60 m for Ichkeul). In the deeper sites (SBR, Chitane, Edku, Burullus, and Manzala), an Ekman grab sampler was used to estimate plant cover. For the other sites, a quadrat (50×50 cm) was used.Water depth (if applicable) and percentage species cover were noted in each quadrat.

Plant distributions
Specific composition of the aquatic plant communities was generally related to the water level and to the water quality but species distributions were very heterogeneous and depended also on more specific ecological factors such as substratum, length of exposure, inundation and grazing. The seasonal variations in water depth along each vegetation transect (Figure 5) show that changes were least at the Delta Lakes (data only shown for Manzala) and relatively large at Zerga on the Atlantic Moroccan coast where tidal changes are marked. No standing water was present at Bokka after mid 1998.

Morocco
For SBR changes in spatial and temporal distributions of the three characteristic plant species were marked (Figure 6). The fringing emergent vegetation zone was often dry and consisted of a continuous belt of *Juncus maritimus* and *Panicum repens*, 1–3 m wide, and occasionally mixed with patches of *Juncus acutus, Scirpus lacustris, Typha angustifolia, Phragmites* and *Mentha rotundifolia. Typha angustifolia* and *Phragmites communis* communities were more developed on the west shore (cf., Atbib, 1979–1980). The submerged vegetation zone is restricted to a distance of 25–30 m around the lake (to a depth of ~150 cm). Four macrophytes were seasonally common: *Ruppia cirrhosa, Naias marina, Chara aspera* and *Chaetomorpha linum* (Figure 6) and their abundances changed according to the biologic cycle. *Ruppia cirrhosa* constituted a large belt up to 30 m wide on the east shore and cover was greatest in the spring and early summer and it dies back in the humid season leaving bare patches of the surface substratum. *Naias marina* grows over a short cycle (June–September) and this species was unrecorded by Atbib (1979–1980).*Chara aspera* grew from January–June and after April it formed a discontinuous belt, 20m wide, and during the summer tended to occupy the space used by *Naias marina. Chaetomorpha linum* grew from late spring and through the summer and formed large marginal patches. Together, *Ruppia, C. aspera* and *C. linum* provide important shelter zones for zooplankton and invertebrates (from predatory birds (ducks and coots), fish (including *Cyprinus carpio*), and insects (Ramdani, 1980, 1982; Campredon et al., 1982).

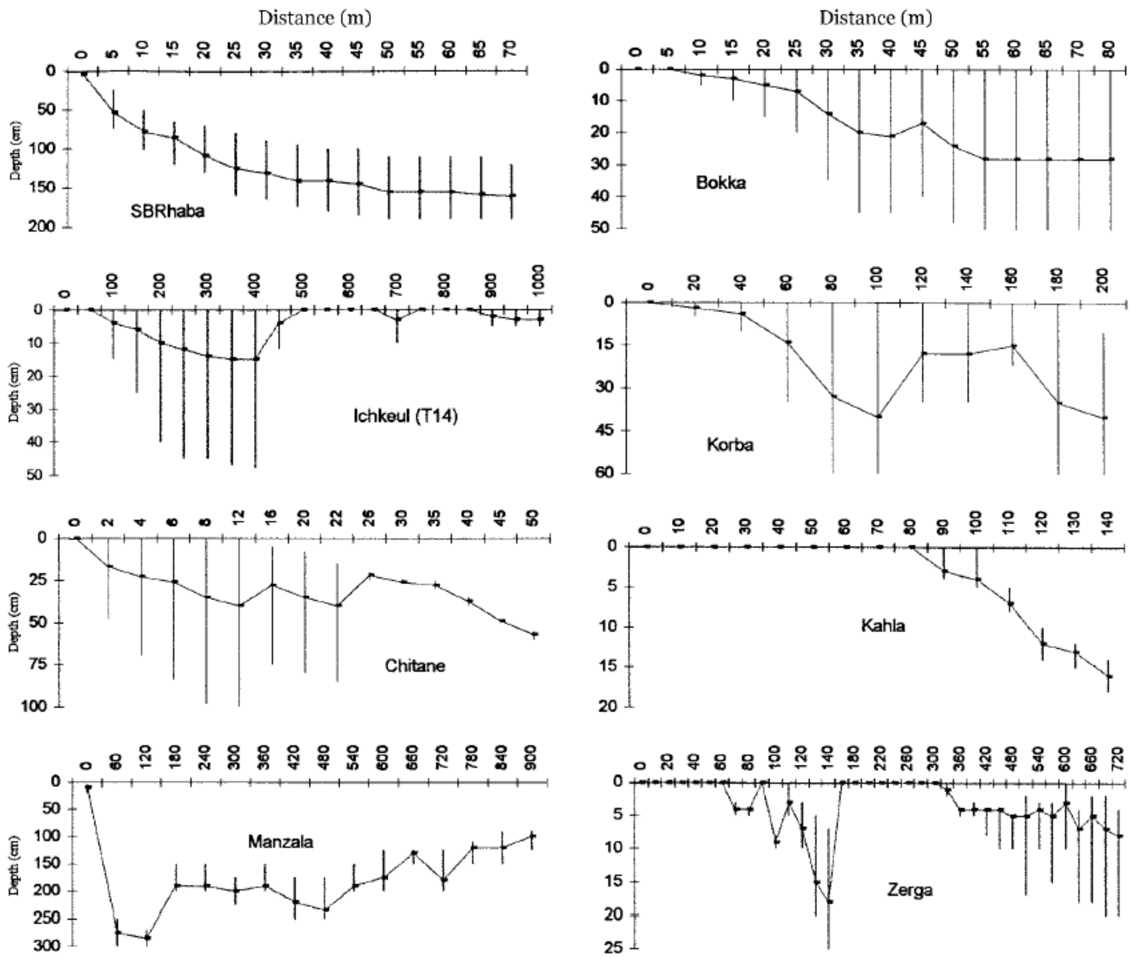


Figure 5. Depth variations measured along the vegetation transects (see Figures 1–4) in each of the each CASSARINA site during the period of monitoring (1997–1998). Mean values in cm are indicated by each curve and error bars indicate the maximum and minimum seasonal variation. (Data for Burullus and Edku not shown.) Note that in late 1998 Bokka was drained and became a dry basin.

In *Merja Zerga* the flora was characteristic of salty humid zones and here vegetation dynamics essentially depend on soil hydromorphy and inundation time. The vegetation is mapped (Dakki et al., 1997) and the lagoon possesses a large belt of marginal vegetation dominated by *Sarcocornia fruticosa* (50–140 m wide). The entrance of the Nador canal (see Figure 1) was characterized by a patchily distributed slightly brackish water flora (*Potamogeton, Scirpus lacustris, S. maritimus, Typha angustifolia, Phragmites communis, Juncus acutus, J. subulatus, J. articulatus, Cynodon dactylon*). The vegetation transect chosen for this survey (see Figure 1b) crossed a *S. fruticosa* salt marsh. Sampling at 10 m intervals revealed no significant seasonal variation in the plant cover composition (Figure 6). The transition zone at 120–140 m from foreshore to tidal flats reflected the inundation limit. The foreshore community was composed of *Sarcocornia fruticosa, Atriplex portulacoides, Suaeda fruticosa, Atriplex tataricus, Hordeum maritimum* (in dryer soil), *Samolus valerandi* and *Spergularia salina. Sarcocornia fruticosa* cover varied between 40 and 90% over the first 120 m and was often monospecific. Standing water (a few cm deep) started at ~130 m where *Chaetomorpha linum* and *Enteromorpha compressa* (with *E. intestinalis*) were present. A depression (at 130–140 m) was completely flooded by high tides to 5–20 cm depth. The transect (prolonged in December 1998 to 720 m) showed that *S. fruticosa* extends more than 500 m but was absent from 140–220 m where green algae proliferated. In the second *S. fruticosa* zone (240–680 m), cover was lower (5–25%) and mixed with algae (*Chaetomorpha linum, Enteromopha compressa* and *E. intestinalis*) and the grass *Aeluropus littoralis* (which formed circular patches, 5–7 m in diameter, between 480–720 m). *A. littoralis* is a good food source for coots, geese, swans, ducks, and cattle and probably indicates occasional influence of freshwater from Nador canal. Beyond ~720 m, the permanent shallow water of the merja began and macrophytes were largely absent. *Zostera noltii* and *Ulva lactuca* are common in the 'gullet' and some *Zostera* occurs in centre of the lagoon and occupies the shelly mud flats with *Ruppia cirrhosa, Enteromorpha intestinalis, Ulva lactuca*, and *Cladophora*.

Merja Bokka possessed a sporadic belt of aquatic vegetation, about 30 m wide and to a depth of ~20 cm in 1997–1998. The eastern shore was often dry with small patches of *Juncus maritimus*. Encroaching agricultural activity was threatening the better-developed vegetation on the western side in 1997. On this shore, *Juncus acutus, Scirpus lacustris, Lythrum hyssopifolia, Typha angustifolia, Phragmites communis, Mentha rotundifolia, Rumex palustris, Ampelodesmos mauritanica*, and *Panicum repens* were frequent. These species were also recorded here by Emberger (in Le Coz, 1964). *Typha angustifolia* and *Tamarix* sp. were best developed on the west shore during February–September 1998. However, by late August 1998 the whole lake was drained and in early 1999 all aquatic vegetation was virtually eliminated. A major change resulted: the area was planted in late summer 1998 with crop plants (sunflower *Helianthus annuus*) (Figure 6). Before the water was lost, carp (*Cyprinus carpio*) and by water birds (ducks and coots) grazed *Panicum repens. Chara vulgaris* (a common plant in alkaline Moroccan waters (Elkhiati, 1987, 1995) grew January–June 1997–1998 with greatest cover from April to May when it formed a discontinuous belt ~40m wide. Other aquatic plants of note were patches of *Lemna minor* and *Azolla filiculoides* in May 1998 and of *Rumex palustris* in the summer of that year.

Tunisia

The small acidic lake *Megene Chitane* supports a rich community of aquatic plants. The marginal zone (Figure 6) comprised large patches of *Juncus acuti- florus, J. heterophyllus, Panicum repens, Aeluropus littoralis, Lotus ornithopodioides, Typha angustifolia*, and *Nymphaea alba* and *Cotula* spp. *Typha* and *Nymphaea* were more developed on the North and West shore during March–September 1998. *Lemna minor* formed small patches during the spring period. *Nitella opaca* has completely disappeared from this site during the monitoring period (1997–1999) but its oospores are common in the sediment (Birks et al., 2001; Ramdani et al., 2001b). *Isoetes velata* grew in a 8 m wide belt with a maximum cover of 80%. *Juncus acutiflorus* occurred between 12–50 m and *Nymphaea alba* was associated with the deeper water (Figure 6). The seasonal variations were associated with water level fluctuations with levels changing by >80 cm seasonally. In August 1998 water depth was reduced to ~20 cm in the central zone where *Typha* had begun to colonize. Plants in Chitane provide an important shelter zone for invertebrates and the common amphibians (*Rana* and *Hyla*).

Garaet El Ichkeul vegetation transects were mainly conducted on the exposed lake shore where *Sarcocornia fruticosa (=Arthrocnemum fruticosum), Juncus subulatus, Ammi visnaga*, and *Frankenia laevis* often dominated (Figure 6). Elsewhere, *Tolypella glomerata, Callitriche* sp., *Potamogeton pectinatus* and *Zannichellia palustris* grew in fore-shore depressions. *Chaetomorpha linum* and *Enteromorpha intestinalis* occurred within the lake. *Ruppia cirrhosa* develops during the summer (Morgan & Boy, 1982; Kraïem & Ben Hamza, 2000) but Stevenson (1991) demonstrated that *Potamogeton pectinatus* was replaced by *R. cirrhosa* (near CASSARINA transect T3) in the late 1980s. Also the formerly extensive marsh *Scirpus* marshes (to 1989) were (in 1997) occupied by terrestrial ruderals (e.g., *Sarcocornia, Ammi visnaga* and *Trifolium stellatum*). The 1998 monitoring showed both *Scirpus maritimus* and *S. littoralis* were absent (Figure 7) and that *Ruppia cirrhosa* was well established in the centre of the lake (but with low cover 0–~30% over bare sediment). The two vegetation transects monitored (T3 and T14) were both dominated by *Sarcocornia fruticosa* and *Frankenia laevis* in 1997–1999. T14 was 1100 m long but consisted almost entirely *Sarcocornia* with bare mud (Kraïem & Ben Hamza, 2000). *Frankenia* dominated the foreshore part of T3 (0–240 m) with cover of 5–60%. *Sarcocornia* formed a large belt between 20–540 m with 60–90% coverage. In both transects small residual patches of *Phragmites* indicated potential for *Phragmites* regeneration if salinity is reduced. Until the late 1980s, *Phragmites* formed an extensive marginal fringe around most of the lake shore but by the mid 1990s this had almost disappeared, the zone being marked (in 1997–1998) with dead, occasionally *Balanus* encrusted, stem bases.

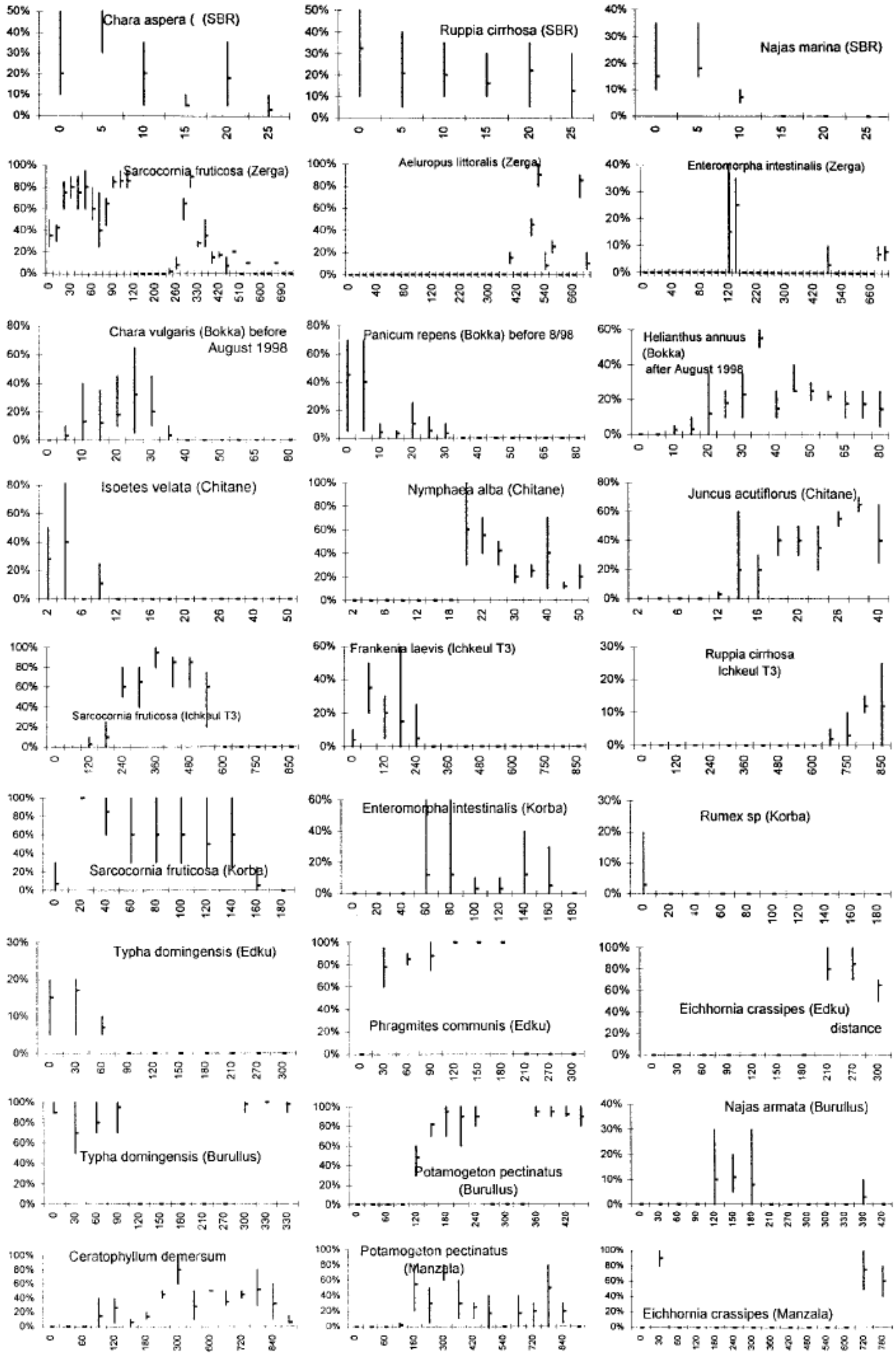


Figure 6. Variation in percentage cover of the dominant plant species along the vegetation transects at each of the nine CASSARINA sites. Curves refer to the average cover estimated for the monitoring period (1997–1998) and error bar maxima and minima refer to seasonal cover changes during this period. Distance (x axis) is in m.

In *Korba Lake* (Figure 6) a dense mat of green algae, *Enteromorpha intestinalis* and *Chaetomorpha linum*, frequently covered submergedwestern and central regions in 1998. The western shore consisted of an extensive *Sarcocornia fruticosa* salt marsh that showed little seasonal variation and with a stable water level. *Atriplex* sp., *Melilotus indica, Hordeum marinum*, and *Rumex* sp. were localized on the upper lake shore (Figure 3a). The eastern shore zone was more sandy and here *Lamprothamnium papulosum* (Characaea) was occasionally found in February–June (1998) in shallow water. This plant is rare in Tunisia being recorded at only five sites (Corillion, 1977) and is intolerant of high pollution (Elkhiati, 1995). In April 1998, surface sediment was strongly anoxic on the west side of the lake and in the southern sector, only filamentous green algae flourished in overlying water. Only three common plant species occurred in the transect (Figure 6): *Sarcocornia fruticosa, Rumex* sp., and *Chaetomorpha linum*.

Egypt

Despite major disturbances, the Delta lakes are still primarily characterized by extensive stands of emergent macrophytes (cf., Khedr & Lovett-Doust, 2000) that form valuable refuges for wild-life. At *Edku Lake*, the dominant emergent plants were *Phragmites communis* and *Typha domingensis. T. domingensis* was frequently present as fringing growth along the edges of the main *Phragmites* stands. Frequent channels enclosed by emergent vegetation were colonized by water hyacinth and *Potamogeton pectinatus*. Patches of *P. pectinatus* were occasionally common beyond the reed beds but none occurred in the transect survey. This plant was formerly much more common (Elster & Vellenweider, 1961). The 270-m long transect was mainly composed of three species (Figure 6): *T. domingensis* (20% cover, near the transect start) but *Phragmites* dominated the whole transect (70–100% cover). Temporal and spatial variations were low. *Eichhornia crassipes*, however, formed large patches in open water and increased during the monitoring period.

The emergent macrophytes of *Burullus Lake* (Figure 6) formed a belt 200–330 m wide (in 1997–1998) along the northern shore. *Phragmites* was dominant in the 450-m long transect line but *Typha domingensis* was more abundant than at Edku but water hyacinth was less so. Immediately beyond the reed beds on the northern side of the lake there were extensive patches of submerged *P. pectinatus. Phragmites* began at the northern edge of the lake and continued with little variation until the open water area was reached 360 m from the shore. Because of the semi-permanent nature of the access channel, some modifications of the fringing vegetation had occurred, and channel edges were colonized by *Typha domingensis*; water hyacinth was common. Two species of submerged macrophytes were also common along the transect: *Potamogeton pectinatus*, and *Najas marina* but their % cover was highly variable, mostly due to the seasonal growth cycles.

In *Manzala Lake* (Figure 6) the south-western sector still supports large areas of emergent vegetation with stands of *Phragmites* and *Typha domingensis* and patches of open water partly colonized by water hyacinth. *Ceratophyllum demersum* was locally abundant. The transect began at the water edge by a large raft of water hyacinth (in 1998) and continued along the edge of a large channel kept largely free of vegetation for boat access. In the over-deepened first 100 m (water depth ~2.5 m) only green filamentous algae were common on the sediment and water clarity was low. Several higher plants occurred in the rest of the transect including *Potamogeton pectinatus, P. crispus, Ceratophyllum demersum*, and (rarely) *Marsilea aegyptica. Phragmites* and *Typha* were more frequent at the transect distal end. Some patches of *Eichhornia crassipes* were encountered in the transect and this plant seems to have expanded during the monitoring period but, being a floating plant, estimating its distribution is difficult. Beyond the transect region, in the sediment coring area (see Figure 4), water clarity was high and the submerged vegetation was virtually 100% cover of *P. pectinatus*.

Discussion

The data presented in this study constitute an important base line account of the status of the nine CASSARINA lakes at the end of the 20th century. The results can be considered in several parts: the nature of the lake basins, the lake vegetation and past changes, and the future implications.

Lake basins
Occupying coastal or near coastal locations, the CASSARINA sites are all at or near the termini of catchment drainage systems. However, catchment based inferences are difficult to make because basins are often poorly defined and past land-use practices have caused major modifications of lake-catchment hydrologic pathways. For the Moroccan and Tunisian sites, documentary evidence of past changes is generally sparse and mainly relates to the 20th century (see summary Tables 2 and 3). Early maps indicate, however, that Merja Zerga was navigable in the 17th century (Bleau, 1663). Well-documented changes at Zerga include the construction of the Nador canal and increasing ground-water abstraction (Hollis, 1996); cessation and drainage of Bokka and vegetation changes occurred at all the Moroccan sites. Some of these changes have had profound aquatic ecosystem affects, most notably by increasing siltation and degrading water quality and availability (Flower, 2001; Birks et al., 2001). Sidi Bou Rhaba is entirely ground-water maintained and, interestingly, the site's religious connection may have played a role in its preservation. The surrounding woodland was altered in the 1920s (by *Eucalyptus* planting) but pollen evidence suggests that disturbance was greater before the 20th century (Reille, 1969; Peglar et al., 2001).

In Tunisia, interference with inflows has also had major effects on aquatic ecosystem quality at Chitane and Ichkeul and is also suspected at Korba. Recent salinity changes at Ichkeul by hydrology improvements began at least 100 years ago (Stevenson & Battarbee, 1991) and culminated in the 1980s–1990s by the installation of inflow barrages (Hollis, 1992) and onset of hypersalinity (Table 3) with major effects on the aquatic macrophyte vegetation. There are however future plans to divert more freshwater back to this lake (Kellel, 1979; Ayache, 1988; Kraïem & Ben Hamza, 2000) and recovery is probably possible if sufficient freshwater is re-supplied in a hydrologically regulated manner. Additionally, even if salinity is controlled, until the high turbidity of Ichkeul is reduced (either by re-establishment of appropriate macrophyte zones or by carefully constructed vegetated levees), aquatic productivity and invertebrate diversity will undoubtedly remain low. Biodiversity in Chitane, is particularly important and on-going abstraction of the acid spring water supply is a major and imminent threat to the acidophilous biota of this small lake. On the other hand, intense agricultural activity and associated water abstraction on the western border of Lac de Korba has had little apparent effect on the lake. Here, seawater maintains the lake level but analysis of longer sediment cores could well reveal more freshwater conditions in the distant past. Water pollution from Korba town is a problem but the lake still supports a few Charophytes and many migrant birds, particularly flamingos. The Korba region is currently under consideration for improved environmental management by the state (Kraïem & Ben Hamza, 2000).

Hydrology of the Delta lakes is in marked contrast to the locally defined and intermittent freshwater supplies to the Moroccan and Tunisian sites. The Nile River is by far the main source of freshwater supply with rainfall contributing only around 100 mm annually. The catchment is therefore immense and not definable because all three lakes are also directly linked to the sea and to canals. Large size, especially of Manzala, and the complex hydrological regime resulting from marine and freshwater inflows mean that there are large within-site gradients in water quality (e.g., Khalil & Salib, 1986). These gradients have changed with time and the hydrology of the whole Delta region has been modified by man since Pharonic times (Butzer, 1976). Successive Nile barrages since the late 19th century and the Aswan High Dam in the 1960s (Table 2) have increased freshwater availability for summer irrigation of the Delta region (Shahin, 1985; Shaheen & Yosef, 1978; Fathi & Abdelzaher, 2000). Interestingly, increased supply of Nile water has postponed the probably inevitable salinization of these lakes by on-going Delta subsidence (Sestini, 1992; Stanley & Warne, 1994). Reclamation of land for development and for agriculture together with pollution and unplanned expansion of fish farming are the main current threats to the Delta lakes. The loss of open water indicated by earlier regional maps and remote sensing surveys (Abou El Magd, 1995) is alarming but reflects an expanding local human population. Most of Egypt's 60 million people are concentrated in the Delta region and the need for new land is intense. New towns are being established and one development is in the environmentally unstable region between Burullus Lake and the Mediterranean (Figure 4, upper). In 1999, the town was partly built but not occupied and consequently this will inevitably have major impacts on Burullus, especially in the region of the CASSARINA vegetation transect. Elsewhere, the urban expansion of Damiatta to the east is taking place on former recent lake deposits of Manzala.

Lake vegetation
During the 20th century, both emergent and submerged vegetation were important parts of the lake ecosystem at the CASSARINA sites. At three sites (Ichkeul, Zerga and Bokka) CASSARINA transect monitoring has shown that aquatic marginal vegetation has been partly replaced by terrestrial elements or had disappeared entirely by the late 1990s. Canalization and barrages on the inflows around Ichkeul (Hollis, 1992; Kraïem & Ben Hamza, 2000) during preceding decades have greatly diminished the wetland marsh zone by reducing the area seasonally inundated by freshwater (<5 g l^{-1} salinity). Hence the upper portion of the Ichkeul vegetation transects consisted entirely of halophytes and ruderal plants (in 1997–1999). Inflowing water was totally eliminated from Bokka in 1998 and the catastrophic failure of the aquatic system was monitored (Ramdani et al., 2001a, b). This failure emphasizes the problems facing many of the smaller wetland lakes in agricultural regions of North Africa. Similarly, Chitane is currently diminishing through reduced water supply caused by local irrigation needs (Kraïem & Ben Hamza, 2000). Although the lake still supports aquatic vegetation, *Typha* had invaded the central lake region in 1998 and *Cotula* sp. has colonized much of the expose littoral zone. Restoring an adequate lake water level is clearly essential if the biodiversity value of this site is not to decline further.

Ruppia cirrhosa is probably the most common submerged aquatic plant in the more brackish lakes of Morocco and Tunisia. This plant flourishes in Sidi Bou Rhaba and has become abundant in Ichkeul where it has replaced *Potamogeton pectinatus* since the 1980s (Stevenson, 1991; Hollis, 1992). This plant is now well-established in Ichkeul and is distributed mainly in the western part of the lake where it has little effect on reducing turbidity. Charophytes are particularly diverse macroalage and although they are generally intolerant of pollution, they were formerly common in Bokka (Birks et al., 2001) and *Lamprothamnium papulosum* persists in Korba (1998). *Najas armata* occurred in the Delta lakes but *N. marina* was present in Sidi Bou Rhaba. In the Delta lakes, submerged plants are common but often display a patchy distribution (e.g., *Potamogeton pectinatus* and *Ceratophyllum demersum* along the transect lines). In the vegetation transect areas, the water was turbid with suspended sediment and algae at all three lakes. Plants were few in the near-shore section of the Manzala transect (doubtless caused by past dredging for canal construction), however, in the centre of the SW basin (the sediment core location, Figure 4), *P. pectinatus* provided 100% cover and the Secchi disc depth exceeded water depth. This water clarity is attributed to the stabilization of bottom sediments and the absence of serious eutrophication. It is well known for European lakes that nutrient enrichment and phytoplankton development suppresses growth of submerged macrophytes (e.g.Moss, 1983). In brackish lakes, stability switches between high turbidity and clear-water aquatic macrophyte systems are different (Scheffer, 1998) but the change is probably now occurring in some regions of all the Delta lakes. Nevertheless, the flourishing benthic macrophytes remaining in the central-southwest part of Manzala are good evidence that relatively low disturbance areas persist. These regions provide habitats essential for good *Tilapia* fisheries and should be conserved.

Reed beds of *Phragmites/Typha/Juncus* are particularly important for stabilizing shore regions and providing habitats for nesting birds. The transect surveys show that reed beds are now effectively absent at Merja Zerga, Ichkeul, Merja Bokka and Korba in the late 1990s. Historical data (including Hollis, 1992, 1996; Peglar et al., 2001) indicate that these communities were probably widespread at the first three sites, at least until the middle of the 20th century (see Table 2). At Ichkeul, the post-1980s loss of fringing *Phragmites* was marked and a comparison of dominant vegetation on the Joumine marsh (cf., Figure 2) sample in transects carried out in 1986 and 1998 shows a complete change from *Scirpus* to *Salicornia* domination of the shore zone (Figure 7). A vegetation change on a shorter time scale (1997–1998) has occurred at three sites. By calculating differences in the percentage cover change of the three most common species over the 1997–1998 monitoring period (Figure 8), sustained changes are revealed for Ichkeul and particularly for Chitane and Bokka where 50% cover changes have occurred in the littoral over this period. Conversely, the marginal vegetation is little changed at the Delta lakes during the survey period where reed beds are still locally extensive and diverse. Furthermore, historical evidence (Abou El Magd, 1995; Birks et al., 2001) indicates for Lake Manzala that reed cover of open water areas and islands has increased in recent decades. This change could be beneficial for pollution since more extensive reed cover is probably isolating local pollution problems. In the SW part of Manzala Lake, sediment contamination is minimal (Peters et al., 2001), yet in the eastern part gross water and sediment contamination (Khalil & Salib, 1986; Siegal et al., 1994) has greatly diminished habitat quality and reduced aquatic biodiversity. Because of the isolating role of the emergent macrophytes there are regions, particularly in Burullus and Manzala, that probably remain amongst the most extensive and biologically diverse aquatic sites in North Africa today. The Delta lakes nevertheless contain several introduced species *Eichhornia* and *Azolla filiculoides*, often in great abundance. Being unattached, these plants are difficult to survey with fixed transects but remote sensing offers a useful monitoring tool (Flower et al., 1998). *Eichhornia* was introduced in the 19th century and now constitutes a major problem in the Delta (Tackholm & Drar, 1950; Gay & Berry, 1959; El-Sherif, 1993) but interestingly it is absent in Tunisia and Morocco.

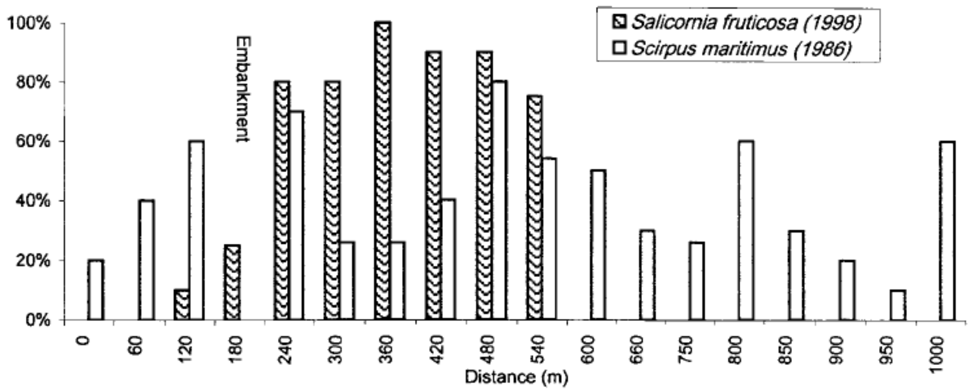


Figure 7. A comparison of the dominant plant cover distribution on transect T3 (see text) at Garaet El Ichkeul (east shore, see Figure 2) in 1986 (data from Stevenson 1991) with data collected in 1998. No *Scirpus* was found in 1998 and note the proliferation of *Salicornia* (=*Arthrocnemum*) in the mid shore zone during the intervening period.

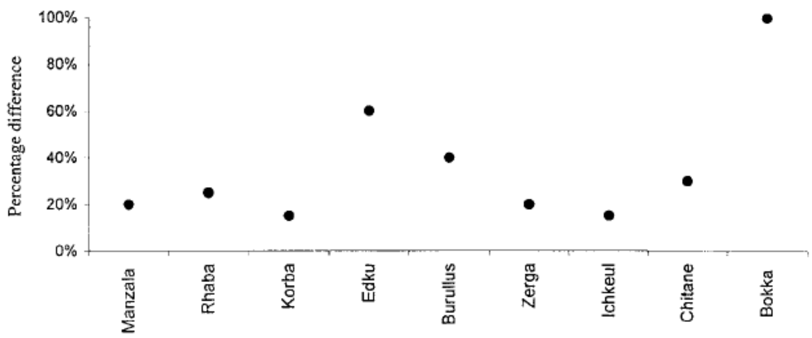


Figure 8. The percentage change at each vegetation transect calculated (the percentage difference between the mean high and low % cover of the three most common plants) for all nine CASSARINA sites for the seasonal monitoring period 1997–1998. Note that the percentage difference was 40% or greater at three sites (see text). Note, differences for Edku were mainly attributable to floating aquatic plants.

Contemporary status and future considerations

By describing some of the basic characteristics of the CASSARINA sites in a co-ordinated manner (cf., Ramdani et al., 2001b; Fathi et al., 2001) for the late 20th century, environmental baselines are available by which future changes can be assessed. Clearly, all the CASSARINA sites are impacted by land-use related human activities to varying degrees. With current population pressures it is unrealistic to foresee rigorous protection of these sites, especially of the larger multi- use lakes (Merja Zerga, Ichkeul, and the Delta lakes). Here, reconciling human usage for agriculture and development with aquatic ecosystems sustainability, productive fisheries and diverse habitats for water birds is a long-term conservation goal. Effective management of these valuable resources is only possible with integrated planning and administration (Dugan, 1993; Davis, 1994; Farinha et al., 1996; Dakki & Elagbani; 1997; Dakki et al., 1997; Bayed et al., 1997; Benessaiah & Belhaj, 1999) but informed decisions can only be made with a sound knowledge of ecosystem dynamics based on extensive monitoring. The spatial scope of the CASSARINA Project is clearly inadequate for evaluating spatial gradients in the larger North African wetland lakes and this should be addressed in future studies. Remote sensing/ satellite surveillance, at least of open water and emergent vegetation areas (cf., Flower et al., 1998), combined with verified species-level lake survey, offers a promising way to undertake integrated lake monitoring and management in the 21st century.

Conclusions

All nine CASSARINA sites are shallow (<2.5m deep) coastal or near coastal wetland lakes that range in size from 0.03 to □ 1000 km2 and several are important bird reserves (Sidi Bou Rhaba, Zerga, lchkeul, Korba, Burullus, and Manzala). During the 20th century, human activities through reclamation and hydrologic modifications, mainly for agricultural purposes, affected all the CASSARINA sites. The loss of lake area by reclamation is substantial for the Nile Delta lakes (Edku, Burullus and Manzala) in the latter half of the 20th century. Water abstraction and reduced inflows have caused lower levels in Ichkeul and Chitane during and after the 1980s. The drainage of Moroccan Merja Bokka was so effective that the entire site was under cultivation by late 1998. Despite the area loss by reclamation, irrigation improvements in the Delta region have caused an excess of fresh Nile water which has resulted in a general freshening of lake waters, probably since at least the 1920s. Conversely, winter flooding was a problem in some agricultural regions of Morocco and Tunisia, and in the 1940s and 1950s river canalization and drainage programmes were undertaken so that 'excess' freshwater was delivered to many coastal wetland lakes, in particular Zerga and Ichkeul. Documentary evidence and transect monitoring indicated major changes occurred at Ichkeul, Bokka, Chitane and Zerga. Only at the relatively undisturbed Moroccan Nature Reserve site, Sidi Bou Rhaba, and in the relatively undisturbed (vegetation transect) regions of the three Delta lakes, reed-bed vegetation (*Phragmites, Juncus*, and *Typha*) has flourished since the late 1990s. Aquatic plants characteristic of softwater (e.g., *Isoetes velata*) were only found at the smallest site (Chitane) where they remain fairly common in shallow water, despite recent site disturbance and falling water levels. Being acidic, this Tunisian site has considerable significance for National aquatic biodiversity. Despite still possessing considerable resource value, the remaining CASSARINA sites are all facing considerable anthropogenic stress. In the future this stress is likely to increase and spatial scale monitoring, especially of the larger sites (for seasonal and inter-annual changes in lake area and in aquatic plant cover and water quality) is a key future requirement for effective integrated environmental change assessment.

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