Zooplankton (Cladocera, Ostracoda), Chironomidae and other benthic faunal remains in sediment cores from nine North African wetland lakes: the CASSARINA Project

Aquatic Ecology **35:** 389-403, 2001.

Mohammed Ramdani[1], Roger J. Flower[2], Najat Elkhiati[3], with contributions from Hilary H. Birks[4], MohammedM. Kraïem[5] and Adel A. Fathi[6]

[1]*Institut Scientifique, Dept. Zoologie et Ecologie Animale, Charia Ibn Batota, B.P. 703, 10106 Rabat, Morocco (Fax: +212 7 77 45 40; e-mail: ramdanimohamed@yahoo.fr);*
[2]*Environmental Change Research Centre, University College London, 26 Bedford Way, London WC1H OAP, UK;*
[3]*Faculté des Sciences Ain Chock, Dept. Biologie, km 8 Route d'Eljadida, BP 5366, Casablanca, Morocco;*
[4]*Botanical Institute, University of Bergen, Allégaten 41, N-5007 Bergen, Norway;*
[5]*Facult´e des Sciences, Dept. de Biologie, Campus Universitaire, 1060 Tunis, Tunisia;*
[6]*Department of Botany, University of El Minia, El Minia 61111, Egypt*

Accepted 10 April 2001

Key words: Chironomidae, Cladocera, Foraminifera, North African wetland lakes, Ostracoda, sediment cores

Abstract

Palaeolimnological studies were carried out on sediment cores from nine North African wetland lakes. The lakes represented a variety of habitats ranging from freshwater to mixohaline conditions and with and without direct connections to the sea. Sediment cores were examined for records of recent environmental change during the 20th century period. Faunal remains analysed in the sediments included those of Cladocera, Ostracoda, Chironomidae, Mollusca and, at the sites with marine connections, Foraminifera.

Cyprideis torosa littoralis was the most common ostracod, occurring in sediments from the seven sites linked with the sea and also in brackish water Sidi Bou Rhaba. In acid Megene Chitane ostracods were scarce, being represented by a single species *(Cypria ophtalmica). Candona neglecta* completely disappeared at two sites (Sidi Bou Rhaba and Bokka) during the 20th century. Of the Cladocera, *Chydorus sphaericus* was common in the moderately mixohaline sites and but *Heterocypris salina* occurred only where marine salinities were occasionally achieved (in Zerga, Ichkeul and Korba). Micro-invertebrate assemblages in the Nile Delta lake cores and to a less extent in Zerga showed a clear response indicative of fresher conditions occurring during the latter part of the 20th century. However the freshening trend began prior to construction of the Aswan High Dam (mid 1960s).

With the exception of the most saline site (Korba), micro-invertebrate communities at all the CASSARINA sites have experienced major disturbances during the 20th century. Changes in freshwater availability associated with increased human usage of water resources is perceived as a major factor regulating the abundance and occurrence of aquatic micro-invertebrate species at these sites.

Introduction

Many of the aquatic invertebrates inhabiting wetland lakes in North Africa are well adapted to fluctuating environmental conditions. At many of these sites the crustacean fauna (Ostracoda, Cladocera, Phyllopoda,) and Diptera (Chironomidae) are particularly well represented (Ramdani et al., 2001b) and most species have wide environmental tolerances and very widespread distributions. North African shallow lowland lakes are typically brackish to some extent with particularly marked variations in salinity (Gauthier, 1928; Ramdani, 1980, 1982, 1986, 1988). Common micro-invertebrates are *Cyprideis torosa littoralis, Eucypris virens, Chydorus sphaericus*, *Daphnia magna, Alona* spp., *Sarscypridopsis aculeata* (e.g., Ramdani, 1988) and usually, where marine links exist, formaniferans are frequently abundant. Together with chironomids and molluscs, North African wetland lakes typically support a wide diversity of aquatic animals. However, the persistence of local populations is often threatened by disturbance and changes in water availability and quality. One way to assess changes in these populations over time scales in excess of several years is to use sediment records (e.g., Hofmann, 1983, 1987, 1987a; Frey, 1964, 1976; Berglund, 1986).

Recent environmental changes can often be inferred from micro-invertebrate analysis of dated lake sediment cores (Whiteside, 1970; Whiteside & Swindall, 1988; Whitmore et al., 1996). Many of these studies are concerned with eutrophication, wetland area developmental histories and with climate change (Frey, 1964, 1976; Hofmann, 1983, 1984, 1985; Brooks & Birks, 2000). Furthermore, sediment records are particularly variable for revealing past diversity changes that help understand the dynamics and development of the faunal communities at specific sites (e.g., Hofmann, 1983, 1984, 1985). Although Copepoda and Rotifera are particularly poorly preserved in lake sediments (Dussart, 1967), biostratigraphic analysis of animal and plant remains is probably the most convenient way of providing long term records of variation of species abundances in aquatic communities. However, in the North African region where brackish lake sediments are typical (e.g., Alcala-Herra et al., 1999), such studies are relatively few.

In this study, autecological stratigraphic analysis of micro-invertebrate remains was undertaken on sediment cores collected from nine North African lakes. These sites are part of the CASSARINA Project (see Flower, 2001) and all are impacted to various extents by human activities. Documentary records concerning aquatic micro-invertebrates are generally poor and it is therefore pertinent to access past changes using palaeolimnological techniques. Biostratigraphic analyses should where ever possible be complemented by bibliographic information. Thus for this study, the results of modern crustacean faunal surveys in Tunisia (Gauthier, 1928; Dumont et al., 1979), Morocco (Ramdani, 1980, 1982, 1986, 1988), Italy (Margaritora, 1983), Egypt and Sudan (Guerney, 1911; Dumont et al., 1984 and others) were consulted. The overall aim of this work is to reveal trends in ecosystem responses to environmental stresses in a region where human land use activities are often intense and have been sustained over many decades.

Sites, materials and methods

Sediment cores from three lakes, each in Morocco, Tunisia and Egypt (see Flower, 2001 and Ramdani et al. (2001a) were collected using a piston corer with 7.4 cm diameter PVC tubing operated from an anchored inflatable boat. At Merja Bokka, the sediment was unusually consolidated, so a standard Livingstone corer (Livingstone, 1955) was used. Sediment cores were taken towards the centre of each site, except for Burullus where an additional core (BULR2) was collected from a more sheltered bay near the north shore. The nine lakes and the core characteristics and locations are listed in Table 1.

The cores were sectioned at 1 cm intervals with every alternate sample being used for analysis of micro-invertebrate remains (see Ramdani & Elkhiati, 2000). Preparation of samples followed a standard method modified from Frey (1986). In each case 10–15 g of fresh sediment were deflocculated in 100 ml of a 10% KOH solution, on a stirring hotplate. To remove the silt fraction, the samples were sieved through 50 μm mesh and the small exoskeletal fragments retained. Residues were repeatedly rinsed until the rinsing water was clear. The remains of Crustacea, chironomid head capsules, molluscs and foraminiferans were picked out of the fraction under a stereomicroscope, usually at x20 magnification, and then mounted as permanent slides.

The faunal remains were identified and counted under a microscope at x20–40 magnification. Results were expressed as numbers per volume (10 cm^3) of sediment and plotted as stratigraphic abundance diagrams, using Tilia software (Grimm, 1991). The sediment material was stored in 5% formaldehyde and nomenclature/taxonomy followed Margaritora (1983) and Hofmann (1978) for the Cladocera, Hofmann (1983, 1984, 1986, 1987a) for the Chironomidae, and for the Ostracoda, Ghetti & McKenzie (1981), Paula & Moutinho (1983) and De Deckker (1981).

Table 1. The CASSARINA wetland lakes, detailing site codes, sediment core length (of the master cores used for sediment dating, see Appleby et al., 2001) and geographic core locations (GPS coordinates). All cores were collected in 1997 except IDKU1 which was collected in 1998. Note BULR2 was not used for microinvertrebrate analysis

Lake	Country	Code	Core length (cm)	Geographical position
Sidi Bou Rhaba	Morocco	RHAB2	214	N 34.24065, W 06.67257
Merja Zerga	Morocco	ZERGI	39	N 34.83574, W 06.28536
Merja Bokka	Morocco	BOKK1	116	N 34.37255, W 06.29019
Megene Chitane	Tunisia	CHET1	60	N 37.15276, E 09.09781
Garaet El Ichkeul	Tunisia	ICHK2	98	N 37.16754, E 09.62393
Lac de Korba	Tunisia	KORB1	42	N 36.61016, E 10.89130
Edku Lake	Egypt	IDKU3	55	N 31.26611, E 31.21092
Burullus Lake	Egypt	BULR1	35	N 31.42063, E 30.63400
Burullus Lake	Egypt	BULR2	70	N 31.43164, E 30.63755
Manzala Lake	Egypt	MANZ1	53	N 31.29561, E 31.88191

Results

Biostratigraphic diagrams were constructed for the zooplankton and benthic faunal remains counted in all nine sediment cores (Figures 1–9). Biostratigraphic zones were selected to indicate faunistic changes thought to be significant. Dates of each sediment core follow the chronologies given in Appleby et al. (2001).

Morocco

Sidi Bou Rhaba

The zooplankton and benthic fauna in core RHAB2 sediment comprised twenty-six species (Figure 1). The species were all characteristic of Mediterranean fresh and brackish water wetlands (Gauthier, 1928; Flossner, 1964; Ghetti & McKenzie, 1981; Margaritora, 1983). Down-core species changes are not large but gradual changes in some abundance profiles allow the core to be zoned. Three stratigraphic zones are indicated on Figure 1 and overall the small abundance shifts indicate less saline conditions persisted at the core base (pre-20th century, zone C).

Within the lower salinity zone C, the Ostracoda *Potamocypris arcuata, Sarscypridopsis aculeata* and *Eucypris virens* and the Cladocera *Ceriodaphnia dubia* are mainly dominant. These taxa all tend to decline in the upper zones. A few valves of *Candona neglecta* (not shown in Figure 1) were rarely found but only in this zone and further indicate fresher conditions before the 20th century. *Cyprideis torosa littoralis* (mainly as juveniles) and *Oxyurella tenuicaudis* were very common in the upper samples (zones A and B). *Cyprideis torosa littoralis* is found in a wide range of salinity from almost freshwater to over 60 g l^{-1} in inland ponds, lakes, and lagoons (Gauthier, 1928; Ghetti & McKenzie, 1981; Ramdani, 1982, 1988). Its reduced presence below 1 m depth in the RHAB2 could well be related water quality change (slightly lower salinity in this zone and possibly an ionic shift away from Na-Cl ions). The virtual absence of adult forms in the upper 0.5 m (excluding the top 15 cm) could relate to possible predation changes (cf., Jeppesen et al., 1996). Black bass were introduced to the lake in the 1950s (Ramdani et al., 2001a) and the salinity of the lake is now probably a little too high to support this fish.

Oxyurella tenuicaudis is a widespread cladoceran species (Holarctic and Neotropical lakes) but is not very common in North Africa (Ramdani, 1986). In Morocco, it is encountered only at Sidi Bou Rhaba. *Chydorus sphaericus* prefers lake shores rich in vegetation (*Chara, Ceratophyllum*, and *Potamogeton)*. It is also often found with Cyanophyta blooms and can tolerate low dissolved oxygen saturation (down to 3%) and water pH values between 3.4–9.2 (Frey, 1986). It filters seston (diatom and flagellate phytoplankton) and its presence in the upper sediments could indicate slightly higher salinity and possibly some eutrophication (Figure 1). Chironomid and Mollusca species tend to be characteristic of eutrophic and deeper fresh and brackish waters in North Africa (Ramdani & Tourenq, 1982). Their frequencies in the core present no clear evidence of major declines of salinity or alkalinity (cf., Tourenq, 1975). *Chironomus halophilus* is however slightly more frequent after 1950s possibly again indicating a trend towards brackishness.

The recent faunal assemblages in this core appear to reflect within-lake habitat features and only secondarily indicate local or regional climate effects. Frequencies of the better preserved species of Cladocera, Ostracoda and Chironomidae are poorly correlated with local annual rainfall and temperature for the past 30 years (Ramdani & Elkhiati, 2000). The changes suggest that Sidi Bou Rhaba has become slightly more saline, probably as a result of ground water changes. The site is coastal and undoubtedly receives wind borne sea salt but the absence of foraminiferans in the sediment profile indicates a lack of any direct marine communications or with the near by Sebou estuary (see Ramdani et al., 2001a).

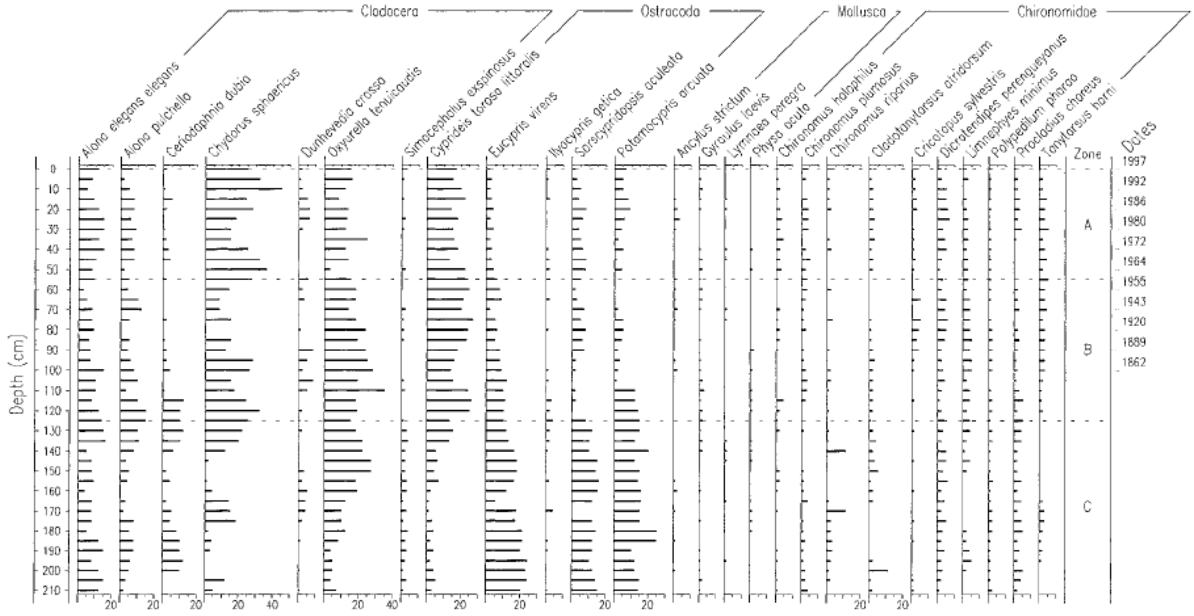

Figure 1. Biostratigraphic distributions of zooplankton and benthic faunal remains in core RHAB2 from Merja Sidi Bou Rhaba, Morocco. Radiometric dates are taken from Appleby et al. (2001).

Merja Zerga

The analysis of ZERG1 reveals twenty-two species of aquatic invertebrates present in the core (Figure 2). The majority of species are from aquatic communities typical of strongly brackish water but the core (from the southwest corner of the lagoon) shows a mixture of marine species and brackish water taxa. Indeed, *Scrobicularia plana*, *Cerastoderma edule* and the foraminiferans are typical tidal lagoon species but *Loxochonca elliptica* (Ostracoda) tolerates a large range of salinities and frequents coastal swamps, estuaries and lagoons (Ghetti & McKenzie, 1981; Athersuch et al., 1989). *Physa acuta* and *Mercuria similis* tolerate brackish conditions but are more typical of freshwaters (mainly streams, lakes, and dams). *Daphnia longispina* and *Potamocypris arcuata* are also typical of freshwater and brackish water sites. They were probably brought into the coring site area by inflowing freshwater. Species in zones A and B reflect both marine tidal and freshwater sources and this section coincides with the period of sediment accumulation following construction of the freshwater drainage channel, Canal du Nador (in the mid-1950s, Ramdani et al., 2001a). This brings freshwater and silt to the Merja and the canal flows into the southwest region of the site, not far from the coring site.

The basal zone of the core (zone C) is occupied exclusively by marine or strongly euryhaline species of Foraminifera and Ostracoda. *Loxochonca elliptica* and *Cyprideis torosa littoralis* are mainly dominant in this pre-1950s core section. Foraminifera and molluscans (for full mollusc macrofossil record see Birks et al., 2001) decreased progressively in the period following construction of the Nador Canal (1950s). This is consistent with the introduction of fresher conditions after the mid 1950s (Figure 2). Additionally, terrestrial plant taxa (see Birks et al., 2001) also increased in the core after the canal was opened and herbaceous species were probably brought in by the canal water. The freshwater organisms deposited in ZERG1 may also have arrived in this way. However, the lagoonal character of the site is clearly marked by the animal assemblages throughout the core. The marine influence remains important in this part of the lagoon, despite the considerable contribution of freshwater, especially in winter.

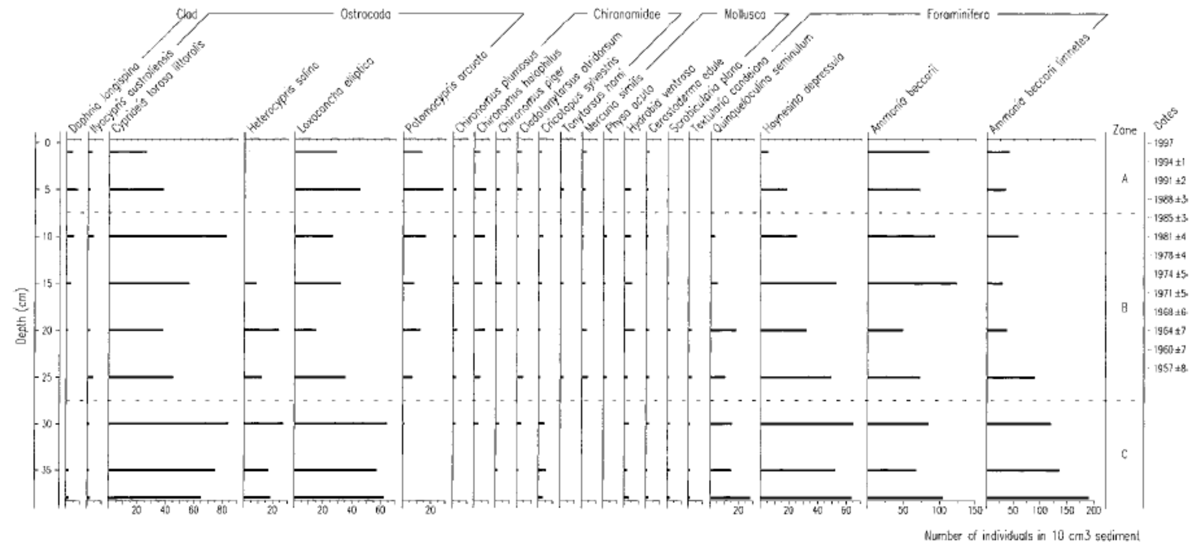

Figure 2. Biostratigraphic distributions of zooplankton and benthic faunal remains in core ZERGI from Merja Zerga, Morocco. Radiometric dates are taken from Appleby et al. (2001). Clad = Cladocera.

Merja Bokka

More than twenty-four animal species were identified in core BOKK1 (Figure 3). They are all typically frequent in alkaline freshwater ecosystems and are poorly represented or absent in strongly brackish waters. Zone D at the core base shows dominance of *Candona neglecta* (Ostracoda) and this species declined from above about 100 cm depth and disappears in the upper zone (zone A), after the 1950s. This probably indicates progressive disturbance of the site by agriculture, especially in recent decades by shallowing and by water quality change (see Ramdani et al., 2001a). The absence of Chydorid species in zones D and C was unexpected and suggests that preservation was relatively poor. Daphniidae ephippia (only) were however present throughout these zones indicating permanent and deeper water. The presence of *Lymnaea peregra, Gyraulus laevis* and *Ancylus fluviatilis* in zone C also suggests permanent freshwater water conditions during this period. This zone, immediately prior to the 20th century, is characterized by increased abundance of *Sarscypridopsis aculeata* iand lower abundances of *Candona neglecta*. *Ilyocypris getica* (Ostracoda) appears in zone C; it prefers permanent streams and can tolerate slightly brackish conditions (Gauthier, 1928). Interestingly, *Bulinus truncatus* (a vector of bilharziasis in the Rharb area) is present in the two basal zones only. The absence of Cladocera Chydoridae in these zones and the presence of mollusc taxa could reflect past connections with the Tiflet stream and with River Sebou (see Ramadani et al., 2001a).

Zone B corresponds with the period 1900–1950s and the lake was probably more permanent and partially isolated from River Sebou floods (following regional agricultural improvements, Le Coz, 1964; Ramdani et al., 2001). The Cladocera (Chydoridae) appear (Figure 3) after ca. 1900 and coincide with dramatic decreases in *Candona neglecta*. *Eucypris virens, Potamocypris variegata, Sarscypridopsis aculeata* and *Chydorus sphaericus* (Cladocera) became progressively more common since ca. 1900, indicating more eutrophic conditions, higher salinity, and possibly better preservation. Increased water usage including improved agricultural irrigation at this time could explain these changes (cf., Le Coz, 1964; Ramdani et al., 2001a).

In zone A (0–14 cm) and dated to post-1965, the lake changed dramatically. *Candona neglecta* disappeared completely and was replaced by a major increase in *Sarscypridopsis aculeata* and *Potamocypris variegata* together with *Alona pulchella* and *Daphnia magna. Daphnia carinata* appears in this zone and indicates temporary shallow water (Gauthier, 1928; Margaritora, 1983; Ramdani, 1988). Although Cladocera and ostracods increase in abundance, *Alona pulchella* largely dominates the zooplanktonic assemblage in this zone. The lake was probably prone to desiccation at this time as all these organisms produce dormant eggs during drought periods. During the last decade, the lake became very shallow and reduced in area as a result of improved regional land drainage. Water stress was exacerbated by the run of drier than average years since 1973. This site was recorded as virtually dry during the prolonged drought of 1981– 1985 but was refilled by 1987 (Ramdani et al., 2001a). Nevertheless, during this period the bulk sediment in BOKK1 changed as red/brown topsoil eroded in from the cultivated areas surrounding the lake (see Flower et al., 2001). From the 1980s, siltation combined with low rainfall and drainage operations caused water level to fall and since late 1998 the site has been dry and under cultivation. Except for the sediment records all traces of the former lake biota are now lost. The site was one of a few Moroccan localities with *Candona neglecta, Alona pulchella* and *Potamocypris arcuata* (cf., Ramdani et al., 2001b).

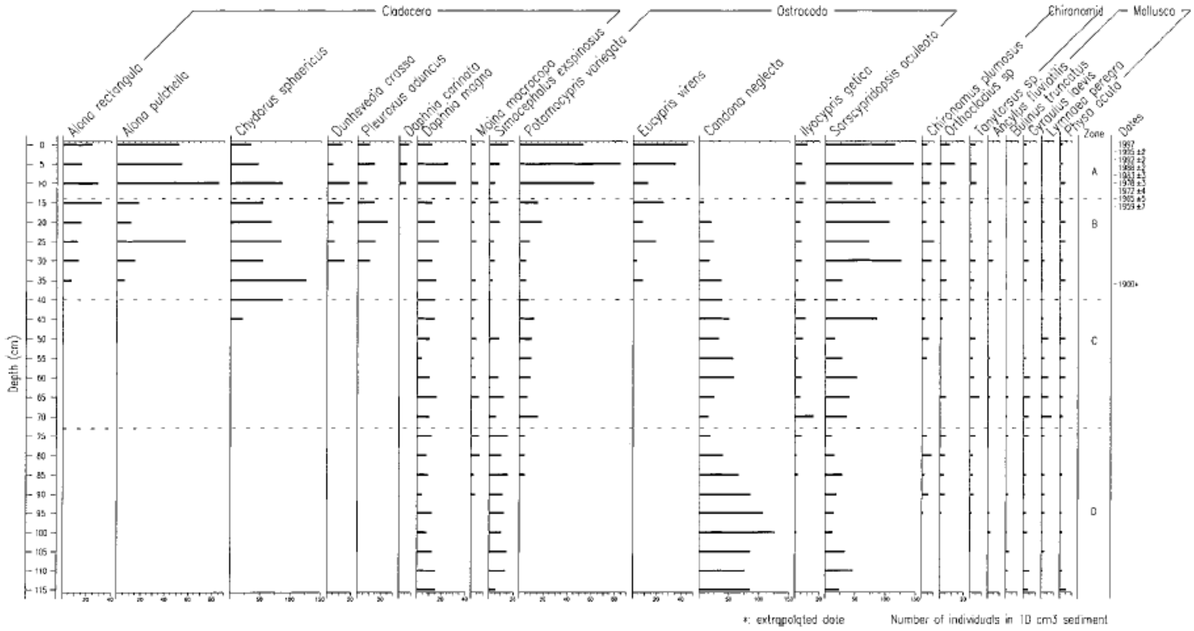

Figure 3. Biostratigraphic distributions of zooplankton and benthic faunal remains in core BOKKI from Merja Bokka, Morocco. Radiometric dates are taken from Appleby et al. (2001).

Tunisia

Megene Chitane

This site is unique in the CASSARINA suite of lakes because it is acidic. The sediment core records the presence of particularly important species of zooplankton that are unusual in freshwater communities elsewhere in North Africa. The stratigraphy of CHET1 (Figure 4) shows an important specific richness of Cladocera (ten species) that reflects the known water quality, the abundance of aquatic plants and the lack of fish predation. Also, the presence of *Graptoleberis testudinaria*, *Leydigia acanthocercoides, Alonella excisa* and *Ilyocryptus sordidus* in the core (all freshwater species) that are favourably influenced by relatively low temperature during the humid season (Gauthier, 1928; Flossner, 1964; Margaritora, 1983; Frey, 1986; Ramdani, 1986).

The faunal remains (Figure 4) indicate that the lake probably experienced three past phases of different water conditions since the 1920s. *Alona rectangula, Chydorus sphaericus* and *Cypria ophtalmica* mainly dominate the basal zone of the core (zone C, 1925–1946). The assemblage in this zone indicates oligotrophy. The second phase (zone B, 1947–1965) is richer in zooplanktonic remains that are preserved in soft, more organic, sediment (see Flower et al., 2001). The presence of *Graptoleberis testudinaria* and *Alonella excisa* indicate perhaps eutrophic conditions and higher temperature (cf., Margaritora, 1983). The upper zone (post mid 1960s) assemblages suggest the onset of eutrophic conditions and some environmental perturbations. Notably, *Graptoleberis testudinaria* and *Tanytarsus* sp. Disappear as *Ceriodaphnia dubia, Chydorus sphaericus, Alonella excisa* and *Diaphanosoma brachyurum* become more common. These changes are doubtless related to small scale agricultural changes but are nonetheless important in terms of aquatic diversity impact. Ostracod species are scarce in CHET1 probably reflecting the acidity of this site, only *Cypria ophtalmica* being present.

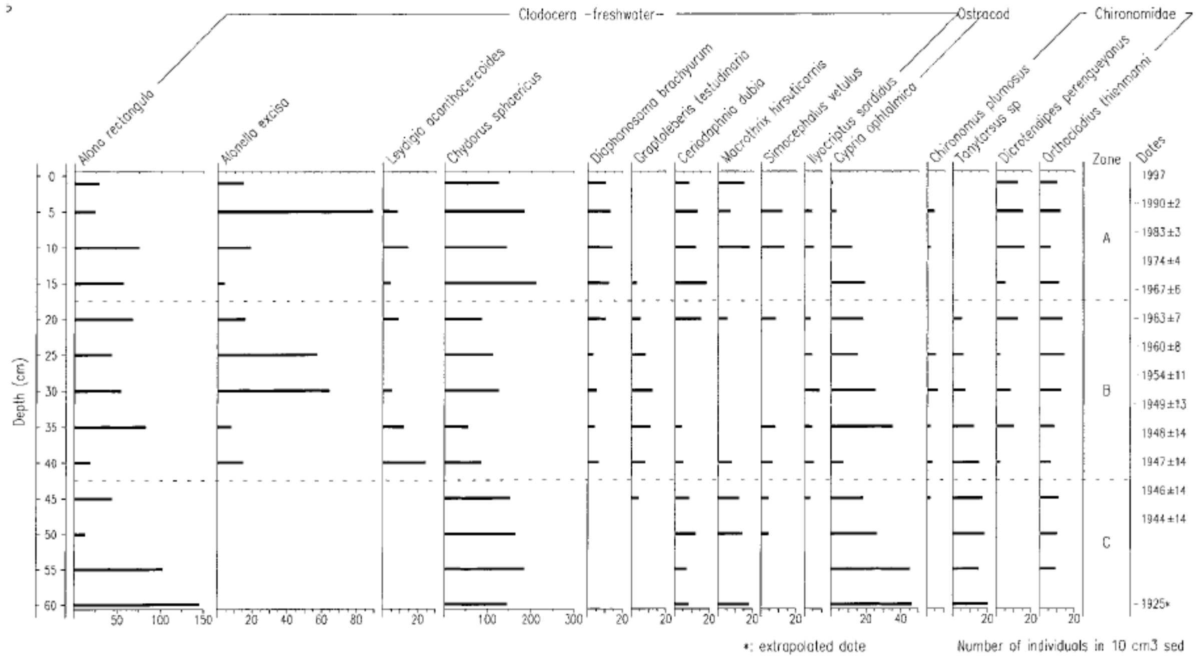

Figure 4. Biostratigraphic distributions of zooplankton and benthic faunal remains in core CHETI from Megen Chitane, Tunisia. Radiometric dates are taken from Appleby et al. (2001).

Garaet El Ichkeul

Zooplanktonic and benthic fauna remains recorded in the upper zone (zone A) of the core ICHK1 (Figure 5) are composed of twenty-two identified taxa. They are a mixture of brackish and marine species. *Cyprideis torosa littoralis, Loxoconcha elliptica, Ilyocypris australiensis Simocephalus vetulus Macrothrix laticornis, Alona affinis, Chironomus halophilus* all indicate brackish water conditions. *Cerastoderma edule, Scrobicularia plana, Hydrobia ventrosa, Heterocypris salina, Loxoconcha elliptica*, *Ammonia beccarii, Ammonia beccarii limnetes*, *Quinqueloculina seminulum, Haynessina depressula* and *Textularia candeiana* indicate marine or strongly brackish conditions.

Brackish-water Cladoceran species are common in the upper zone (particularly in the 1960s period). These indicate a weaker influence of salt water and *Chydorus sphericus* reached maximum abundances around 1980. Gauthier (1928) collected these species of Cladocera and Ostracoda on the western shore of this lake and suggested that they came from the Oued El Maleh inflow. Their presence makes biostratigraphic interpretation of salinity changes difficult. In this profile, most of brackish water species are completely absent before about the 1940s period. This could indicate preservation problems in zones C and D or that the lake winter salinities were lower in the 1970s. Measured values clearly show that the salinity of Ichkeul increased from at least the 1980s (Ramdani et al., 2001a) but this is not marked by supporting faunistic changes in the core. The strong seasonal salinity regime of this lake combined with sediment mixing problems, disturbing the upper sediment (cf., Appleby et al., 2001), all conspire to make interpretation of these profiles problematic.

Marine species (molluscs, foraminiferans, ostracods) dominate ICHK1 lower zones C and D, however, foraminiferans increase in zone C after ca. 1900 to the 1950s (top of zone C). This change indicates more marine conditions, possibly linked with the opening of the seaward channel in the late 19th century (cf., Stevenson & Battarbee, 1991). The forams declined strongly during the 1970s (zone B) and only two species persist in zone A, post ca. 1985. Control of marine inflow since the 1980s (Ramdani et al., 2001a) together with exaggerated summer salinities during the 1990s could be a factor affecting recent foraminiferan abundances. The salinity of Ichkeul has undoubtedly fluctuated markedly in the past (Stevenson & Battarbee, 1991). Nevertheless, it is the loss of the very low salinity winter phase since the mid- 1980s, as a result of water management by barraging the freshwater inflows, which has probably had most effect on the resident lake biota.

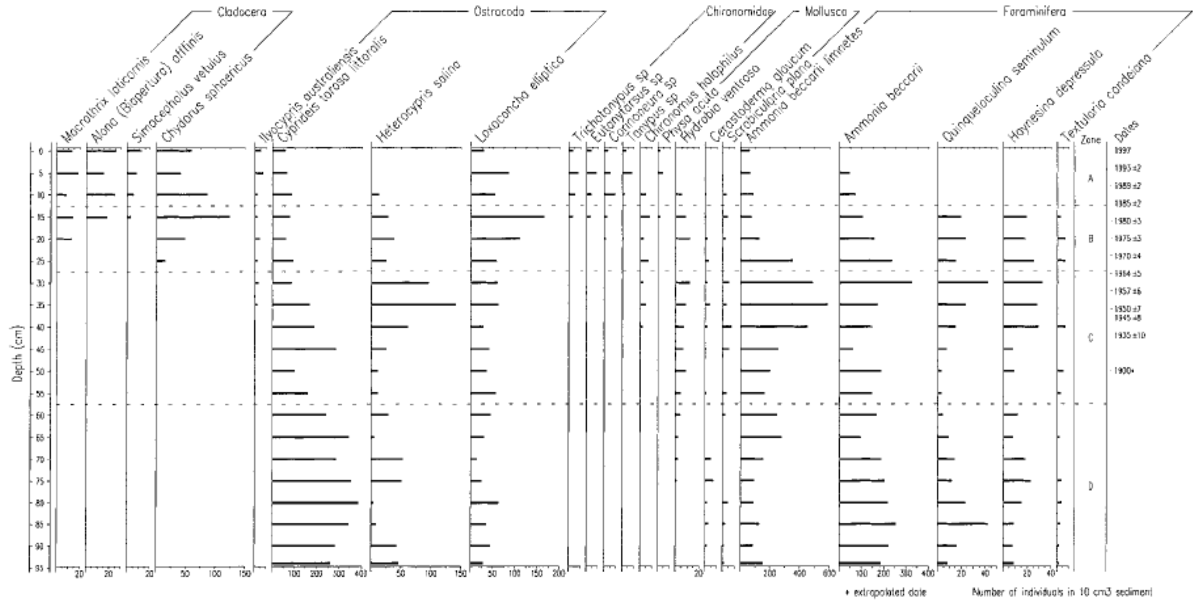

Figure 5. Biostratigraphic distributions of zooplankton and benthic faunal remains in core ICHK2 from Garaet El Ichkeul, Tunisia. Radiometric dates are taken from Appleby et al. (2001).

Lac de Korba

In the core (KORB1) fifteen species constitute the zooplanktonic assemblages. These are all typical of salt water dominated coastal wetlands in the Mediterranean region (Gauthier, 1928; Flossner, 1964; Margaritora, 1983; Ramdani, 1986). Seven species are dominant (Figure 6), *Cyprideis torosa littoralis, Heterocypris salina* and *Loxoconcha elliptica* (ostracods), *Haynesina depressula, Quinqueloculina seminulum, Ammonia beccarii* and *Ammonia beccarii limnetes* (foraminiferans). The chironomid species are chracteristic of strongly brackish and salt water. *Moina salina* (Cladocera) and *Dicrotendipes fisconotatus* tolerate high salinity and were found in the sediment deposited during the last hundred years. Three species of coastal mollusc occurred in the sediment and these are described elsewhere (Birks et al., 2001).

The whole 42 cm long core could represent deposition over the last three centuries, if radiometric dates are extrapolated (cf., Appleby et al., 2001). There is little variation in faunal diversity across the three zones (Figure 6) and species are stable over time. Changes are small and make zonation of the core is difficult but the appearance of a few specimens of two chironomid taxa (*Dicrotendipes fisconotatus* and *Stichochironomus* sp.) and small declines in two ostracod taxa *(Cyprideis torosa littoralis* and *Heterocypris salina).* These suggest that zone A tends to hypersaline, zone B to mesohaline and zone C to oligohaline conditions.

Water quality at this site is strongly influenced by marine conditions and the water becomes strongly hypersaline in summer months through evaporation (Kraïem & Ben Hamza, 2000). The species composition of the planktonic and benthic assemblages in KORB1 do not suggest any special anomalies or major water quality trends occurred at this site during the last hundred years: it has been influenced by high salinity conditions throughout this period. There are some pollution problems in the south part of Korba (Birks et al., 2001) but the micro-invertebrate species present in KORB1 appear to be tolerant of this disturbance.

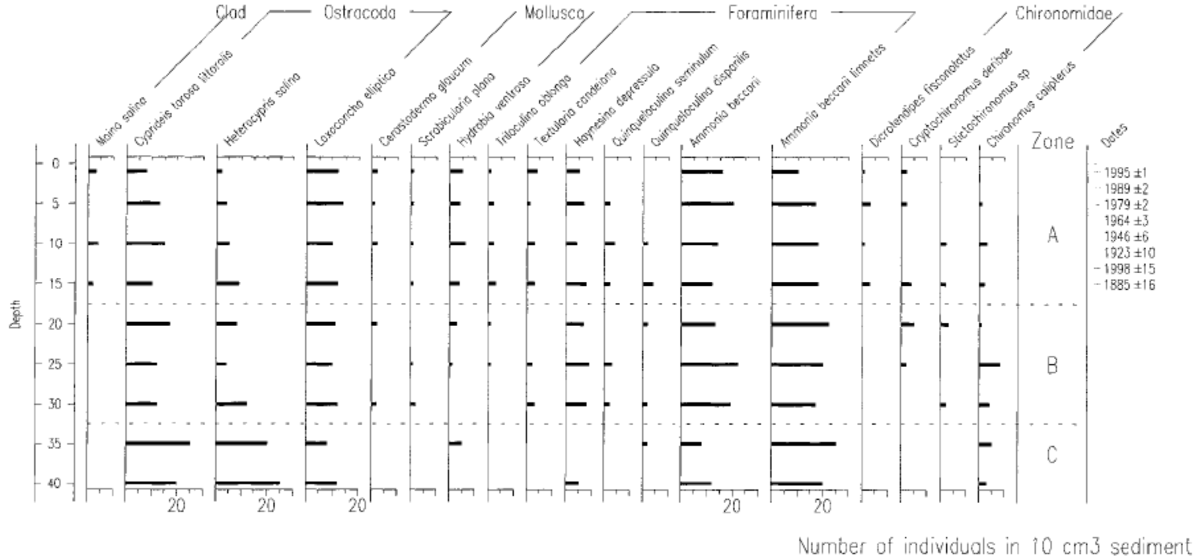

Figure 6. Biostratigraphic distributions of zooplank-ton and benthic faunal remains in core KORB1 from Lac de Korba, Tunisia. Radiometric dates are taken from Appleby et al. (2001). Clad = Cladocera.

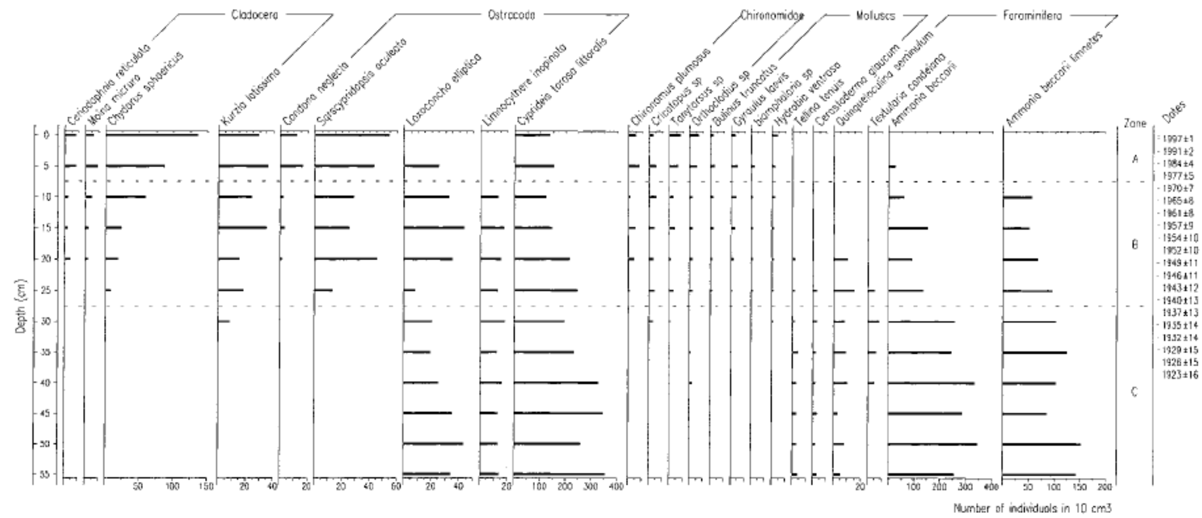

Figure 7. Biostratigraphic distributions of zooplankton and benthic faunal remains in core IDKU3 from Edku Lake, Egypt. Radiometric dates are taken from Appleby et al. (2001).

Egypt

Edku lake

Analysis of core IDKU3 (Figure 7) revealed the presence of twenty-four zooplankton and benthic species. The Cladoceran species *Kurzia latissima, Moina mi crura, Chydorus sphaericus* and *Ceriodaphnia reticulata,* were all well represented in the upper core section and indicate that a predominantly freshwater condition has persisted since the early 1940s. *Chydorus sphaericus*, considered as cosmopolitan cladoceran species, indicates a trend towards water freshening and possibly eutrophication of the lake during these decades. Also, *Candona neglecta* (Ostracoda), is commonly found in freshwater ponds, lakes, marshes, ditches and oligohaline creeks (salinity 0–15 g l–1, Ghetti & McKenzie, 1981). It increases in recent decades and provides good evidence of fresher conditions in Edku. This species (which disappeared from Bokka and Sidi Bou Rhaba) proliferated in Edku where it seems well adapted to recent conditions. Also *Sarscypridopsis aculeata* (in zones A and B), a euryhaline species often common in oligohaline environments, indicates a recent shift to less marine conditions. The 1940s was also a period when the molluscan fauna changed to species more indicative of freshwaters (cf., Birks et al., 2001). The biostratigraphy shows concomitantly a progressive decline in the abundance of foraminiferan abundances during this period; they are virtually absent from the sediment record after the 1970s.

These faunistic changes show that, although connected to the sea, the lake has been strongly influenced by water quality changes since at last the 1940s. These changes are almost certainly the result of hydrological modifications that have delivered more freshwater to the Delta agricultural regions and hence to the lake during at least the 20th century. These changes began before the Aswan High Dam was constructed (1960s) but are nonetheless probably associated with irrigational improvements in this region that began in the late 19th century (El Hawary, 1960; Saad, 1975, 1976a, 1976b, 1978; Ramdani et al., 2001a).

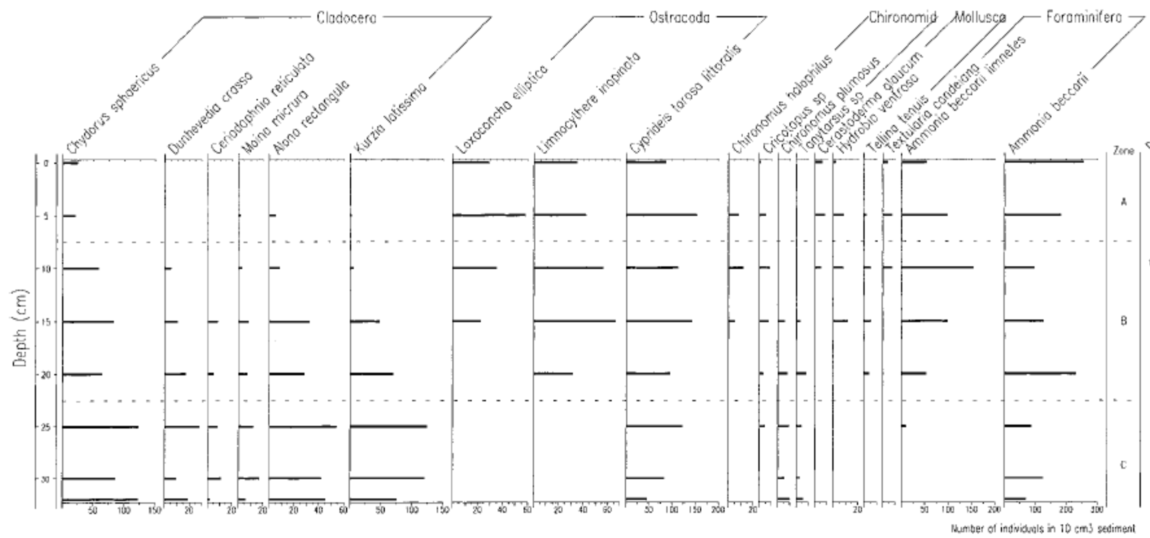

Figure 8. Biostratigraphic distributions of zooplankton and benthic faunal remains in core BULRI from Burullus Lake, Egypt. Radiometric dates are taken from Appleby et al. (2001).

Burullus lake

Twenty zooplanktonic and benthic faunal species remains were found in the BULR1. Distinctly mixed freshwater (*Alona rectangula*, *Dunhevedia crassa, Alona rectangula* and *Moina brachiata*) and brackish water (*Kurzia latissima, Chironomus halophilus, Loxoconcha elliptica*, *Hydrobia ventrosa*) assemblages occur in the core. There is however a quantitative predominance of the brackish water forms that is greater than that found in the Edku Lake core. The presence of marine species (*Cerastoderma glaucum* and foraminiferans) in the upper core confirm to the more brackish character of this site. Brackish water taxa in zones A and B are typically *Cyprideis torosa littoralis, Loxoconcha elliptica, Chirinomus halophilus* and *Ammonia beccarii*. From the base of zone B (22 cm), all the Cladocera species decline. In the most recent period, zone A, which probably represents post 1950s sediment, several cladoceran taxa disappear and at the core top only *Chydorus sphaericus* persists.

Dating is very limited for this core (see Appleby et al., 2001) but most species changes occur between 15 and 20 cm depth, the section that pre-dates the 1950s. Hydrological changes at this time probably promoted the main faunistic changes. The zone B section indicates the most brackish period and the marine molluscs (also see the marginal core, Birks et al., 2001) were present as fragments only in the surface upper 3 cm of sediment. The mixed salinity preferences exhibited by the species recorded in BULR1 (central Burullus) indicate that the ecosystem is currently finely balanced between freshwater and marine conditions. However, the sedimentary faunal record of water freshening during the 20th century is much less marked in Burullus than is indicated by cores from the other two Delta sites.

Manzala lake

This lake sediment core (MANZ1) contained twenty six identified taxa and shows a remarkable transition of species from those which are indicative of salt water to those which indicate more freshwater conditions (in the most recent period). The whole 50 cm core covers more than one century (Figure 9) and has three zones. Basal zone C is marked by a strong presence of brackish/marine species, *Cyprideis torosa littoralis* and foraminiferans, *Ammonia beccarii* and *Ammonia beccarii limnetes.* In zone B, salt water taxa decline progressively and a cladoceran fauna, typical of slightly brackish and freshwater species, appears along with the ostracods, *Potamocypris variegata* and *Darwinula stevensoni* (Figure 9). Zone A is characterized by freshwater species, mainly dominated by cladocerans, foraminiferans being scarce. The most marked changes occur at the start of zone A, around 1960.

On the whole, the zooplankton remains in this lake core suggest that increasingly freshwater conditions developed since the early 20th century. The presence of foraminiferan species *(Ammonia beccarii* and *Ammonia beccarii limnetes)* in low abundances during recent decades and the progressive disappearance of the marine and brackish water taxa is regarded as strong evidence for the increasingly freshwater character of this region of Manzala. As for Edku lake, water management in the intensely agricultural Delta region is considered as the most likely explanation for the increasingly freshwater character of Manzala Lake. A freshening trend for the lake has been reported elsewhere (El Maghraby et al., 1963; El Wakeel et al., 1970; Dumont, 1979; Anonymous, 1987; Athersuch et al., 1989).

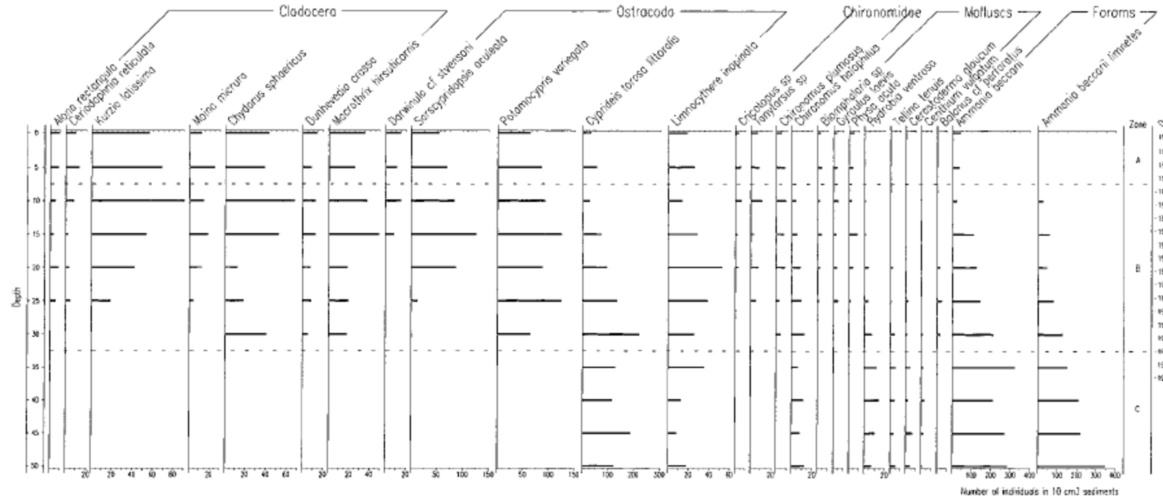

Figure 9. Biostratigraphic distributions of zooplankton and benthic faunal remains in core MANZ1 from Manzala Lake, Egypt. Radiometric dates are taken from Appleby et al. (2001).

Discussion

All the cores from the sampled North African lakes exhibit various degrees of faunal change in the composition of their micro-invertebrate assemblages. Interpretation of the significance of the biostratigraphic profiles depends on several factors that concern both sediment record integrity and environmental change.

Sediment record integrity

Of the various micro- and macrofossil remains that commonly occur in sediment cores, those of zooplankton and benthic animals can offer clear evidence of water quality changes as well as of physical habitat changes and of trophic interactions. However, perhaps more importantly in exploratory studies they serve as biodiversity indicators of past aquatic ecosystem states. At previously uninvestigated sites, only the sediment record offers a reliable guide to those species that contributed to past aquatic ecosystem diversity. Sediment biological records are however nearly always incomplete because of problems of preservation and sample representativity. Probably five groups of zooplankton (*sensu lato*) and benthic fauna comply with requirements for providing (usually) good sediment records: they are Ostracoda, Cladocera, Chironomidae, Foraminifera and Mollusca (Frey, 1960, 1964, 1976, 1986; Stahl, 1969; Hofmann, 1978, 1983, 1984, 1985, 1986b, 1987a, 1987b, 1988). The advantage of these organisms is that their exoskeletal parts – head shields, head capsules and shells – preserve well in most non-acid lake sediments. On the other hand, Copepods, Rotifers and Cladocera, such as Daphniidae, are often less well preserved because their exoskeleton is too fragile to survive turbation and attack by microorganisms. In deeper sediments, only post-abdominal claws, mandibles and ephippia represent the Daphniidae species. Therefore numbers of Daphniidae (poorly preserved) remains in lake sediments cannot be readily translated to the relative abundances in the original living community.

In the North Africa lake sediments, these preservational problems are exacerbated by relatively high water temperature and high biological activity. Records of some groups are clearly missing (e.g. rotifer remains were only fond in surface sediments; ostracods shells were not preserved in acid lake sediments) and some cladoceran records were probably incomplete (e.g., Ichkeul). Nevertheless, preservation appears to be much better than for diatoms in most of the CASSARINA cores (see Flower et al., 2001) and give some confidence in record reliability.

Recent environmental change

Most of the North African CASSARINA wetland lakes have been impacted by human activity during the 20th century. The faunal biostratigraphies presented here provide good evidence not only of large differences in diversity between sites but also, at most sites, of major faunistic changes during the 20th century. These relatively short and generally asynchronous sediment records (of ca. 100 y or less) of invertebrate assemblages in the North African region are probably best interpreted by reference to past human disturbance of the lakes (eutrophication, fish introduction, siltation, contaminants) (e.g., Frey, 1986). The palaeoecological value of micro-invertebrate remains is based largely on the microhabitat specificity and the rapid dispersal and short generation times of most species. These factors enable communities to closely track environmental change at species level and without the time lags associated with some palaeoecological indicators. On the other hand, especially in mixohaline sites, micro-invertebrates tend to be tolerant of wide ranges of water quality types. In the CASSARINA sites for example the extremely euryhaline nature of *Cyprideis torosa littoralis* and *Sarscypridopsis aculeata* makes use of their abundance changes in cores for precise estimations of past salinities difficult. Furthermore, complications for precise reconstructions arise when water quality change promotes new biotic interactions and predation effects. The strong salinity changes that have occurred in several CASSARINA sites are doubtless associated with major changes in food web structure. Additionally species introductions, irrespective of water quality change, may be effective in modifying sediment records. In RHAB2, for example, the lack of adult *Cyprideis* for example in the upper sediments could well reflect introduction of predatory fish (Black Bass) in the 1950s. Predation must often be a factor that is reflected in zooplankton records (e.g., Jeppeson et al., 1996) but in systems where biological, chemical and sometimes physical environmental variables are changing interactively through time, interpreting specific causes of assemblage shifts can be problematic. In such circumstances and especially when extensive modern calibrational data sets are lacking, sedimentary records of past occurrences and abundances of taxa can provide information most relevant to environmental change issues and biodiversity.

This investigation of nine North African lakes has revealed a wide range of responses to 20th century environmental stresses. The main drivers of change are inferred as being salinity and/or water availability. Human disturbance has been the pervasive 20th century issue affecting all these sites and impacts were exacerbated by the seasonally hot southern Mediterranean climate. On the basis of perceived changes in the faunal records, these sites can be divided into three main groups:

(i) Merja Bokka, Megene Chitane and Garaet El Ichkeul are all strongly impacted by human activity associated with hydrological modifications. Merja Bokka no longer exists as an open water site (since 1998) and aquatic micro-invertebrates communities are currently disturbed and degraded at Chitane. Ichkeul was an important international site for birds but its zooplankton record is represented by a mixture of brackish and freshwater taxa with low diversity and low densities. These sites all require hydrological solutions, based on ecological principles, to restore their lost or degraded aquatic biodiversity.

(ii) Lac de Korba, Sidi Bou Rhaba and Merja Zerga are less strongly stressed by human activity but the latter two sites are undergoing more gradual changes of their micro-invertebrate communities. Like the group three lakes, Merja Zerga records disturbances caused by fresher conditions following

diversion of drainage water to the site in the 1950s but marine species persist in the most recent sediment.
(iii) The Egyptian lakes are all influenced by variations in freshwater supply from the River Nile. They generally support considerable diversity that mainly reflects the past and present balance of fresh and saltwater inflows. Despite the trend to fresher conditions, brackish and freshwater species of zooplankton remain mixed in the sediments but Lake Burullus is most affected by seawater and supports the lowest diversity. Lakes Edku and Manzala are mainly dominated by freshwater species that also indicate some eutrophication.

Species richness

Because sediments integrate micro-invertebrate communities over time, they are likely to provide larger species inventories than is obtained by modern 'spot' sampling (see Ramdani et al., 2001b). However, poor preservation can result in under- representation of some species in the sediment record (see above). Zooplankton analysis of open water samples (Ramdani et al., 2001b) revealed the presence of more than 90 species in the combined set of nine CASSARINA lakes. From the sediment core analyses, zooplankton and benthic faunal taxa totalled more than 100 species (despite Copepoda and Rotifera species being unrepresented in sediment cores). Overall, *Darwinula stevensoni* and *Candona neglecta* are regarded as important biodiversity indicators for the quality of wetlands lakes in the region.

Korba, currently the most saline CASSARINA lake (Fathi et al., 2001), supported the lowest diversity of sediment micro-invertebrates (only eighteen species recorded). Recent land use changes and pollution from the near by Korba town appears to have had little biological effect on the fauna. Megene Chitane, Merja Bokka (former), Sidi Bou Rhaba and the Delta lake sediment cores represent high biodiversity systems, mainly dominated by freshwater species. With the exception of Sidi Bou Rhaba, these sites have nevertheless all experienced major biotic changes in the last one hundred years. At Merja Bokka loss of amphibians and appearance of *Daphnia carinata* (characteristics of temporary and turbid hydrosystems in North Africa) marked the final stage in the decline of this lake, which by late 1998 was dry. Megene Chitane also showed dramatic changes in species and the virtual loss of *Cypria ophtalmica*. This site was an important biodiversity resource (see Birks et al., 2001; Flower et al., 2001) since most of the species were adapted to the unusual acid conditions. The lake is under severe threat at present and its biodiversity value will be further degraded if current conditions continue.

Future issues

In the long term, probably none of the nine CASSARINA sites are sustainable without appropriate management to mitigate human impacts. Environmental safeguards are clearly necessary to maintain species abundance balances in these essentially natural ecosystems. In the Delta lakes particularly, zooplankton diversity has generally increased in recent decades but it is nevertheless imperative that effective management to regulate commercial fishing, pollution and land reclamation is undertaken to conserve these threatened but valuable ecosystems. The palaeolimnological investigations carried during the CASSARINA Project have established past variability and species changes and provided comprehensive species level diversity inventories for the 20th century period. These sites remain threatened by human activities in the short term and by climate change in the long term and future research should now be focused on monitoring and predictive modelling to help formulate effective future national amenity management policy.

Conclusions

All the stratigraphic micro-invertebrate sequences described for nine North African lakes were generally composed of cosmopolitan species that are typically adapted to a wide spectrum of environmental conditions. Hydrological modifications of freshwater supplies to these lakes are considered to be the main factor promoting change in the sedimentary assemblages. Assemblages in the Nile Delta lakes show a clear response to fresher conditions occurring during the 20th century.

Here, freshwater species generally increased before and after the Aswan High Dam was built in the 1960s and probably reflect River Nile management for irrigation purposes during the last ca. 100 years. Similarly, Merja Zerga assemblages indicated freshening conditions following land drainage works in the mid 1950s. The faunal records from Merja Bokka,Megene Chitane and Ichkeul all showed major changes associated with lake drainage (Bokka was dry by late 1998) or with reduced inflows (Chitane and Ichkeul). Only in the core from Korba, did the micro-invertebrate assemblages indicate fairly stable ecological conditions during the 20th century.

Acknowledgements

This work was made possible by funding from the European Union under the International Co-operation Scheme, contract number ERBIC18CT960029. In Morocco the Eaux et FôretsMinistry kindly facilitated site access. We are grateful for advice on analysis of micro-invertebrate remains from Drs W. Hoffman, S. Brooks and J. Holmes. Many people helped with the project fieldwork and sediment coring was undertaken by staff from the Environmental Change Research Centre (University College London) including Dr S. Patrick, C. Curtis and E. Shilland.

References

Anonymous (1987) Limnological studies on the Manzalah Lake. Wastewater Re-use Project. Acad. Sci. Research Tech. Nation. Inst. Oceanogr. Fish. 1–85 p

Alcala-Herrera JA, Jacob JS, Castillo LM and Neck RW (1999). Holocene palaeosalinity in a Maya wetland, Belize, inferred from the microfaunal assemblage. Quat. Res. 41: 121–130

Appleby PG, Birks HH, Flower RJ, Rose N, Peglar SM, Ramdani M, Kraïem MM and Fathi AA (2001) Radiometrically determined dates and sedimentation rates for recent sediments in nine North African wetland lakes (the CASSARINA Project). Aquat Ecol 35: 347–367

Athersuch J, Horne DJ and Whittaker JE (1989) Marine and brackish water Ostracods. In: Kermak DM and Barnes RSK (ed.), Synopses of the British Fauna (New series). No. 43, EJ Brill, New York

Azzouzi A and Laville H (1987) Premier inventaire faunistique des Chironomidés *(Diptera)* du Maroc. Ann Limnol 23: 217–224

Azzouzi A, Laville H and Reiss F (1992) Nouvelles récoltes de Chironomidés au Maroc. Ann Limnol 28: 225–232

Berglund BE (1986) Handbook of Holocene Palaeoecology and Palaeohydrology. Wiley, Chichester

Birks HH, Peglar SM, Boomer I, Flower RJ, Ramdani M, with contributions from Appleby PG, Bjune AE, Patrick ST, Kraïem MM, Fathi AA and Abdelzaher HMA (2001) Palaeolimnological responses of nine North African lakes in the CASSARINA Project to recent environmental changes and human impacts detected by plant macrofossil, pollen, and faunal analyses. Aquat Ecol 35: 405–430

Brooks SJ and Birks HJB (2000) Chironomid-inferred Late-glacial air temperatures at Whitrig Bog, southeast Scotland. J Quat Sci 15: 759–764

De Deckker P (1981)Taxonomy and ecological notes of some ostracods from Australian inland waters. Trans Roy Soc South Australia 105: 91–138

Dumont HJ (1979) Biogeography of some components of zooplankton of the Nile and suggestions for future research. Cairo University, 1–82 p

Dumont HJ, Laureys P and Penseart J (1979) Anostraca, Conchostrata, Cladocera and Copepoda from Tunisia. Hydrobiologia 66: 259–274

Dumont HJ, Penseart J and Elmoghraby AI (1984) Cladocera from the Sudan: Red Sea Hills, Jebel Marra and valley of main Nile. Hydrobiologia 110: 163–169

El Maghraby AM,Wahby SD and Shaheen AH (1963) The ecology of zooplankton in Lake Manzala. Alexandria Inst Hydrobiol Fish Notes Mem 70: 1–43

ElWakeel SK, Abdou HF and Wahby SD (1970) Foraminifera from bottom sediments of Lake Maryut and Lake Manzala (Egypt). Bull Inst Oceanogr Fish Alex 4: 98–112

El Hawary MA (1960) The zooplankton of the Egyptian lakes. A preliminary study on the zooplankton of Lake Maryut and Lake Edku. Alexandria Inst Hydrobiol Fish Notes Mem 52: 1–12

Fahti AA, Abdelhazer HMA, Flower RJ, Ramdani M and Kraïem MM (2001) Phytoplankton communities of North African wetland lakes: the CASSARINA Project. Aquat Ecol 35: 303–318
Flossner D (1964) Zur Cladocerenfauna des Stechlinsee Gebietes. Limnologica 2: 35–103
Flower RJ (2001) ChAnge, Stress, Sustainability and Aquatic ecosystem Resilience In North African wetland lakes during the 20th century: an introduction to integrated biodiversity studies within the CASSARINA Project. Aquat Ecol 35: 261–280
Flower RJ, Dobinson S, Ramdani M, Kraïem MM, Ben Hamza C, Fathi AA, Abdelzaher HMA, Birks HH, Appleby PG, Lees JA, Shilland E, and Patrick ST (2001) Recent environmental change in North African wetland lakes: diatom and other stratigraphic evidence from nine CASSARINA sites. Aquat Ecol 35: 369–388
Frey DG (1960) The ecological significance of cladoceran remains in lake sediments. Ecology 41: 684–698
Frey DG (1964) Remains of animals in Quaternary lake and bog sediments and their interpretation. Arch Hydrobiol Beih Ergebn Limnol 2: 1–114
Frey DG (1976) Interpretation of Quaternary paleoecology from Cladocera and midges, and prognosis regarding usability of other organisms. Can J Zool 54: 2208–2226
Frey DG (1986) Cladocera Analysis. In: Berglund BE (ed.), Handbook of Holocene Palaeoecology and Palaeohydrology. Wiley, Chichester, pp. 667–692
Gauthier H (1928) Recherches sur la faune des eaux continentales de l'Algérie et de la Tunisie. Minerva, Alger, 419 pp
Ghetti PF and McKenzi K (1981) Guide per il riconosciemento selle species animali delle aque interne italiane. Ostracodi (Crustacea, Ostracoda). Con Nation Ricerch Aqu 11: 1–83
Grimm EC (1991) TILIA, Version 1.10. Illinois State Museum, Research and Collections Center
Hofmann W (1978) Analysis of animal microfossils from the Grosser Segeberger See (FRG). Arch Hydrobiol 82: 316–346
Hofmann W(1983) Stratigraphy of Cladocera and Chironomidae in a core from a shallow North German lake. Hydrobiologia 103: 235–239
Hofmann W (1984) Stratigraphic subfossiler Cladocera (Crustacea) und Chironomidae (Diptera) in zwei Sediment Profilen des Meerfelder Maares. Cour Forsch Inst Sencke Berg 65: 67–80
Hofmann W (1985) Dynamics of vertical zooplankton community structure in the Plussee: Cluster analysis. Verh Int Verein Limnol 22: 2983–2986
Hofmann W (1986a) Chironomid analysis. In: Berglund BE (ed.), Handbook of Holocene Palaeoecology and Palaeohydrology. John Wiley & Sons, Chichester, pp. 715–727
Hofmann W (1986b) Developmental history of the Grosser Ploner See (North Germany): cladoceran analysis, with special reference to eutrophication. Arch Hydrobiol/Suppl 74: 259–287
Hofmann W (1987a) Cladocera in space and time: analysis of lake sediments. Hydrobiologia 145: 315–321
Hofmann W (1987b) Stratigraphy of Cladocera (Crustacea) and Chironomidae (Diptera) in three sediment cores from the Central Baltic Sea. Int Rev Ges Hydrobiol 72: 97–106
Hofmann W (1988) The significance of Chironomid analysis (Insecta: Diptera) for paleolimnological research. Palaeogeogr Palaeoclimat Palaeoecol 62: 501–509
Jeppesen E,Madsen EA, Jensen JP and Anderson NJ (1996) Reconstructing the past density of planktivorous fish and trophic structure sediment calibration data set from shallow lakes. Freshw Biol 36: 115–127
Kettani K, Vilchez Quero A, Calle Martinez D and Elouazzani T (1995) Nouvelles récoltes de Chironomidés (Diptera) du Maroc: Les Chironomidés de l'Oued Martil (Rif). Ann Limnol 31: 253–261
Livingstone DA (1955) A lightweight piston sampler for lake deposits. Ecology 36: 137–139
Margaritora F (1983) Guide per il riconoscimento delle specie animali delle acque interne italiane. 22:Cladoceri (Crustacea: Cladocera). Consig Nazion Ricerch AQ/1/197 22: 1–169
Paula LF and Moutinho M (1983) Systématique et distribution des ostracodes au Portugal. Publ Inst Zool Fac Sci Porto, 173: 1–32
Ramdani M (1980) Recherches hydrobiologiques sur un plan d'eau des environs de Rabat, la merja de Sidi Bou Rhaba (Maroc). Doctorat 3◦ cycle, 134 pp
Ramdani M (1982) Les entomostracés de la merja Sidi Bou Rhaba. Bull Inst Sci, Rabat 6: 105–117

Ramdani M (1986) Ecologie des Crustacées ‘Copépodes, Cladocères et Ostracodes’ des mares temporaires marocaines. Doct Etat Marseille I, 217 pp
Ramdani M (1988) Les eaux stagnantes au Maroc: études biotypologique et biogéographique du zooplancton. Trav. Inst. Sci. Rabat Zool 43: 1–40
Ramdani M & Tourenq JN (1982) Notes sur les *Chironomides* de la merja Sidi Bou Rhaba. Bull Inst Sci Rabat 6: 179–185
Ramdani M and Elkhiati N (2000) Description of the Moroccan sites, vegetation transects analysis, water chemistry analysis, zooplankton analysis in open water, zooplanktonic and benthic fauna analysis of the primary sediment cores from the nine CASSARINA lakes. Unpublished CASSARINA Final Report. Institut Scientifique (Rabat), 121 pp
Ramdani M, Flower RJ, Elkhiati N, Kraïem MM, Fathi AA, Birks HH and Patrick ST (2001a) North African wetland lakes: characterization of nine sites included in the CASSARINA Project. Aquat Ecol 35: 281–302
Ramdani M, Elkhiati N, Flower RJ, with contributions from Birks HH, Kraïem MM, Fathi AA and Patrick ST (2001b) Open water zooplankton communities in North African wetland lakes: the CASSARINA Project. Aquat Ecol 35: 319–333
Saad MAH (1975) Studies on the core sediments of Lake Edku, Egypt. Bull Fac Sci Univ Alex 15: 145–169
Saad MAH (1976a) Core sediments from Lake Burollus (Bahra el Burullus), Egypt. Acta Hydrochim. Hydrobiol 4: 469–478
Saad MAH (1976b) Some limnological investigations of Lake Edku, Egypt. Hydrobiology 77: 411–430
Saad MAH (1978) Core sediments from four Egyptian Delta lakes. Bull Natn Pêches Tunisie 2: 237–345
Stahl JB (1969) The uses of chironomids and other midges in interpreting lake histories. Mitt Int Ver Limnol 17: 111–125
Stevenson AC and Batterbee RW (1991) Palaeoecological and documentary records of recent environmental change in Garaet El Ichkeul: a seasonally saline lake in NW Tunisia. Biol Cons 58: 275–295
Tourenq JN (1975) Recherches écologiques sur les Chironomidés (Diptera) de Camargue. Doct d’Etat, Univ P. Sabatier, Toulouse, 424 pp
Whiteside MC (1970) Danish Cladocera: modern ecology and core studies. Ecol Monogr 40: 79–118
Whiteside MC and MR Swindall (1988) Guidelines and limitations paleoecological interpretation. Paleogeogr Paleoclim Paleoecol 62: 405–412
Whitmore TJ, Brenner M and Schelske CL (1996) Highly variable sediment distribution in shallow wind-stressed lakes: a case for sediment-mapping in paleolimnological studies. J Paleolimnol 15: 207–221