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Conservation of Moroccan Wetlands and Palaeoecological Assessment of Recent Environmental Change: Some Preliminary Results with Special Reference to Coastal Sites

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SUMMARY

1) Biologically important wetlands in Morocco are threatened by environmental changes. Land-use intensification and ground water quality deterioration as well as increased soil erosion are major potential problems.

2) Where expensive routine long-term biological monitoring is inappropriate, palaeoecology and exploration of sedimentary records offer a convenient way of assessing sustained ecosystem changes over a variety of time-scales.

3) Three Moroccan wetlands are selected for preliminary palaeoecological analysis. Two on the west coast, Sidi bou Rhaba and the Merja Zerga (Dayat Roureg) are both national nature reserves and have RAMSAR status as bird sanctuaries. Lac Azigza is an upland oligotrophic lake surrounded by relatively undisturbed cedar/oak woodland.

4) Although incomplete, palaeoecological analysis of cores from each sample area indicates that steady-state ecological conditions do not prevail at any of the sites investigated. Sediment dating reveals that the rate of sediment accumulation has increased at two sites, Sidi bou Rhaba and Lac Azigza. Changes in sediment stratigraphy indicate major changes in sediment sources and deposition have also occurred at Dayat Roureg, a small saline lake at the south-western edge of the Merja Zerga. The carbonaceous particle record at Sidi bou Rhaba reveals strong evidence of atmospheric contamination in this coastal region.

5) The high rate of sediment accumulation (c. 2 cm yr^{-1}) measured in Sidi Bou Rhaba, indicates that the site will be seasonally dry within several decades. The acceleration in sediment accumulation is at least partly caused by increased deposition of carbonate minerals. Soil erosion does not seem to be a problem at this site.

6) In Dayat Roureg (a sub-basin in the Merja system) a rich fen peat is buried below some 50 cm of silts and clays. This siltation of wetland vegetation represents a major loss of habitat quality. Causes of the observed changes could include increased penetration by seawater and/or drainage projects in the early 1950s.

7) Sediment accumulation rate has increased at upland Lac Azigza, probably as a result of accelerated soil erosion. There is also a recent and sustained change in percentage frequencies of the major species of planktonic diatoms in the sediment core. The changes begin during the mid-1970s and indicate a small but ecologically significant change in water quality over the past 15 years. The change seems to be unrelated to inter-annual lake level fluctuations and increased human disturbance of the lake catchment is the most likely cause of lake ecosystem instability.

8) Diatom analysis of cores from the coastal wetland sites as well as the collection and analysis of long cores from sites within the Merja Zerga are required to fully evaluate the impacts of recent environmental change at these sites.

9) Information about sustained rates of ecological change and the composition of past and present communities is essential if management authorities are to conserve important wetlands effectively. Palaeoecological methods provide the most appropriate means of obtaining such information.

1. INTRODUCTION

The importance of conserving ecologically valuable wetlands has received global recognition in recent decades. However, problems of implementing appropriate conservation management can be acute in developing countries and Morocco is no exception. The Moroccan government authorities have nevertheless promoted significant improvements in environmental management in recent years, particularly of forest and water resources under the direction of the Division de Eaux et Foret.

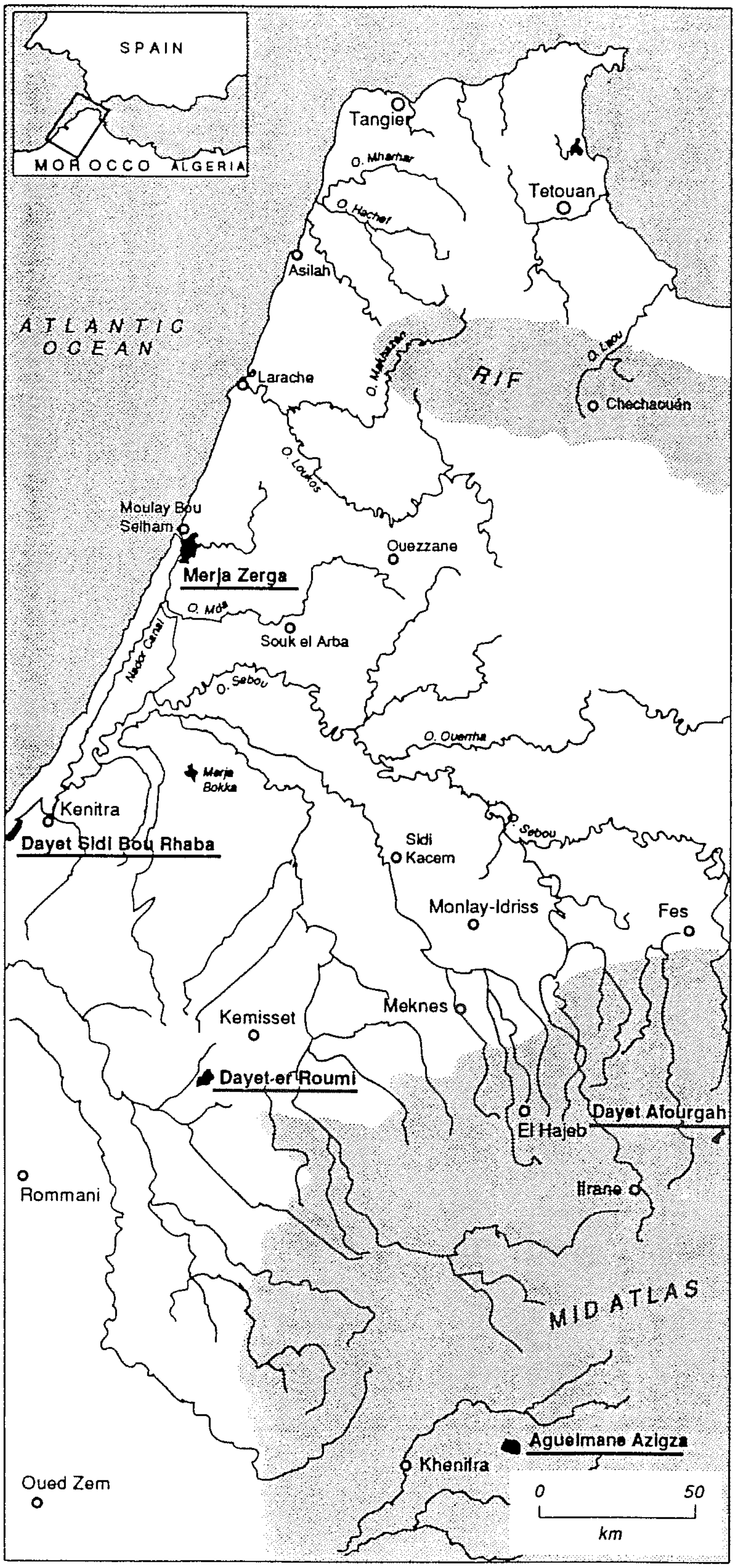
Since the turn of the century many sites, particularly in the Gharb plain of north-eastern Morocco, have come under increasing pressure from land drainage, afforestation and intensive crop production (Swearingen 1987). One result of this land-use intensification is a decline in the water table and a deterioration in ground water quality (Margat 1961), changes which directly threaten the ecology of nearby wetlands. Elsewhere in Morocco, land-use changes have resulted in often severe vegetational disturbance and have greatly accelerated soil erosion (eg. Mikesell 1960, Flower *et al.* 1988). Any likely changes in climate will also adversely effect Moroccan wetlands and coastal sites are particularly vulnerable.

Morocco currently possesses several internationally important wetlands and it is essential for nature conservation that their biological quality is maintained. These environments are not only highly sensitive to the effects of land-use intensification but also to climatic change. Any sustained declines in water depth and water quality will result in loss of biological diversity and habitat degradation. In the absence of long-term biological and chemical monitoring gradual degradation of natural habitats cannot be assessed directly. Exploration of sedimentary records can however offer a reliable way to measure the impact of environmental change over a range of time scales and so allows the current ecological status of valued sites to be evaluated in respect to past conditions.

Since long-term biological and water quality records are generally not available, the only source of relevant information is in the sedimentary record. Microfossil and geochemical analysis of radiometrically dated sediment cores from lakes and wetlands can reveal the nature, timing and magnitude of past changes in natural communities and indicate causal factors. Trends in environmental change reconstructed over past decades can provide information about ecosystem responses that are essential for future management of these sites. Since diatoms are algae which are good indicators of water salinity and nutrient concentrations (eg. Battarbee 1986), analysis of their siliceous remains in sediment cores is a useful way of revealing past trends in water quality change.

This report describes three important wetland sites in Morocco and presents preliminary results of a palaeoenvironmental investigation, with special reference to sediment dating and diatom analysis. The sites are Sidi Bou Rhaba, Merja Zerga and Lac Azigza. The first two of which have RAMSAR status as bird reserves while Lac Azigza supports a particularly rich flora and fauna (Gayral & Panousse 1956).

Figure 1 **Site location map**



2. STUDY SITES

Coastal wetlands

The two coastal wetlands in the Gharb which are particularly important for conservation are Sidi bou Rhaba and the Merja Zerga (Figure 1). Both wetlands are RAMSAR sites, they are internationally renowned for their migratory wildfowl and are recognised as biological reserves by the Moroccan Government.

a) Sidi bou Rhaba (Figure 2)

This lake is located in small valley, lying parallel to the coast, formed by sand dunes. These dunes are consolidated and well vegetated on the eastern side but largely unconsolidated on the seaward side. The lake has no surface inflows or outflows and is saline; salinity fluctuates on a seasonal basis with highest valves, up to around 12% in the open water, occurring in late summer (Ramdani 1981). At this time much of the southern portion of the lake is exposed as a white deposit of carbonate and chloride salts. Most of the lake margin is fringed with *Phragmites* and *Juncus*. The lake is surrounded by woodland which mainly comprises of *Phillyrea angustifolium* on the west side and more mixed stands on the east side including *Pistacia lentiscus*, *Juniperus phoenicea*, *Populus alba*, and *Olea europea* (Atbib 1977). In addition, there are several small plantations of *Eucalyptus* around the lake. This woodland, together with the open and permanent water of the lake, attracts a considerable variety and abundance of birds and is a particularly important site for migratory birds of which over thirty species visit including, European ducks (c. 3000-5000 in number), Squacco, purple herons, great flamingoes, Montague's harriers and avocets (Thevenot 1976, Bergier & Bergier 1990). Away from the lake, the *Juniperus* woodland supports a colony of the north African race of magpie, *Pica pica mauritanicus* (Birkhead 1990), as well as several species of passerines. Despite some tree plantations and construction of access roads, the lake and its surrounding vegetation are relatively undisturbed and the area was designated a biological reserve in 1962.

In addition to its avifauna, Sidi bou Rhaba has been relatively well studied in several other respects, including its contemporary water quality and fauna (Ramdani 1981), vegetation (Atbib 1977), ecology (Lacoste 1984). There is one study of its vegetational history (Reille 1979), but this latter work is concerned with changes over the past 5,000 years rather than the post-1900 period in detail.

b) The Merja Zerga (Figure 3)

This extensive wetland lies some 75 km north of Sidi bou Rhaba (Figure 1); it is a much larger system and is directly connected to the sea. It lies in a depression of Quaternary fine-grained sediment and is delimited from the sea on its western margin by a large unconsolidated dune complex. The freshwater catchment area is large and poorly defined; much of the land is used for crop production and low quality grazing. The Merja is fed by two main inflows, the Nador Canal from the south and the Oued Dradar from the east. The open lagoon is divided into two very shallow depressions, the larger Merja Zerga and the Merja Khala to the north-east. The main lagoon is connected directly to the sea by a 3 m deep channel and at low water, when freshwater inflows are small, open water beyond the drainage channels is only a few centimetres deep. At low tide extensive areas of mud flats are exposed. The -shallow central plane of the Merja is largely covered with aquatic macrophytes, notably beds of *Zostera* marine grass which form the main feeding grounds for visiting wildfowl and waders. Emergent reed beds were formerly widespread but now are mainly limited to the southern perimeter of open water.

The hydrology and salinity of the Merja is dominated in summer by the tidal regime but in winter freshwater inflows contribute to water level (Beaubrun 1976). In January 1971 tidal salinity changes were studied in the in Merja Kalha, the northern sub-basin of the Merja Zerga (Beaubrun 1976), and showed that salinity changed from near that of seawater at high tide to less than 10% at low tide. Hence, salinity of the lagoons fluctuates daily and is determined by the relative quantities of seawater and freshwater inflows.

The Merja Zerga is particularly important for migratory birds with up to 200,000 birds visiting the site each year and was designated a biological reserve in 1978. The site receives about half the total number of ducks and small waders over-wintering in northern Morocco and the numbers of great flamingoes (>6000) and spoonbills (c. 100) are particularly notable (Bergier & Bergier 1990). Passerines and raptors are also common and the site supports breeding populations of some species.

The palaeoecology of the Merja has not been studied but aspects of its hydrobiology are reported by Ramdani (1981). The site has been subject to considerable past disturbances. In recent years the supply of freshwater to the Merja has diminished with a consequent drop in water level (Ben Said, pers. comm.). In the late 1940s and 1950s drainage schemes were started in the Gharb region to prevent winter flooding. The Nador Canal was constructed and introduced into the southern end of the Merja in 1953. The canal initially transported large quantities of eroded soils during wet winter months and the canal mouth is now partly silted. The artificial drainage system is now less effective and in summer months delivers no freshwater to the Merja. Water abstraction, mainly for agricultural purposes, has also reportedly diminished the freshwater inflow from the Oued Drader.

The environmental effects of these land-management changes are largely unknown but they must have modified the ecology and hydrology of the system in various ways. The drainage schemes will have almost certainly lowered the water table in the western Gharb and diminished ground water recharge by freshwater in winter months. Despite an initial increase in freshwater supply by the opening of the Nador channel and an unknown siltation rate in the central lagoon it is likely that the Merja is now subject to higher salinities than in the past. Furthermore, post-1940s land-use intensification in the drained area around the Merja has doubtless lead to an increase in agro-chemicals entering the lagoon.

It is clear that both coastal sites are at risk from salinity changes, siltation and contamination from agro-chemicals through quality changes in ground water and, at the Merja, in runoff water. Sidi bou Rhaba is generally assumed to be ecologically stable but it is very shallow and the siltation rate is unknown. Seawater intrusions occur through geological strata below both sites (Margat 1961) and has a direct influence on the salinity of ground waters. Consequently, a key question is whether there has been a sustained change in the salinities of these lagoons over the past 100 years or so. Furthermore, any future climatic changes will almost certainly exacerbate any current salinity and agro-chemical contamination problems.

Upland wetlands

A site of particular interest is Lac Azigza in the Middle Atlas Mountains (Figure 1). This oligotrophic hardwater upland lake lies in a catchment dominated by natural and semi-natural oak and cedar woodland which is notable for its wildlife diversity (Gayral & Panousee 1956). Several species of duck visit the lake regularly; raptors and the chough (*Pyrrhocorax pyrrhocorax*) inhabit nearby limestone cliffs and numerous passerines breed in the oak/cedar woodland around the lake. The lake has a single deep basin with a maximum depth of 32 m in 1990 (Figure 4). There are some disturbances in the catchment: a house was constructed (c. 1988) at the western end of the lake and a significant population temporarily decamps to the cooler catchment slopes in the heat of high summer; sheep and goat grazing is permitted and could be intensifying. The forest is however protected from exploitation for charcoal production.

Direct effects of agro-chemical contamination and ground water salinity changes at this upland site must be small although inputs of pollutants from the atmosphere is a potential problem as are effects of predicted climatic change. Nevertheless, the lake is sensitive to catchment disturbance and has experienced major changes in water level in the past decade (Flower & Foster 1991). Ecological stability of the site is threatened and it is important to assess the impact of the these processes on the lake ecosystem. We already know from previous sediment core studies (Flower *et al.* 1988) that the siltation rate at Lac Azigza is increasing and the composition of surrounding woodland is undergoing change. Furthermore, the lake biota could now be responding to water quality change resulting from increasing recreation use of the site as well as from the markedly fluctuating water levels.

Table 1　Sidi bou Rhaba, Merja Zerga and Lac Azigza: selected site characteristics

	Sidi bou Rhaba	Merja Zerga	Lac Azigza
Location	34 15' N, 6 40' W	34 50' N, 6 20' W	32 45' N, 5 27' W
Altitude (m)	1.0	0.0	1472.0
precipitation (mm yr^{-1})	596	700	804
Area (ha)	50	3500	37
Maximum depth (m)	1.4	4.5*	32.0

* Refers to the channel, the open lagoon is normally less than 0.5 m deep and is reduced in summer months to a few centimetres depth at low water.

Figure 2 Sidi bou Rhaba: site map

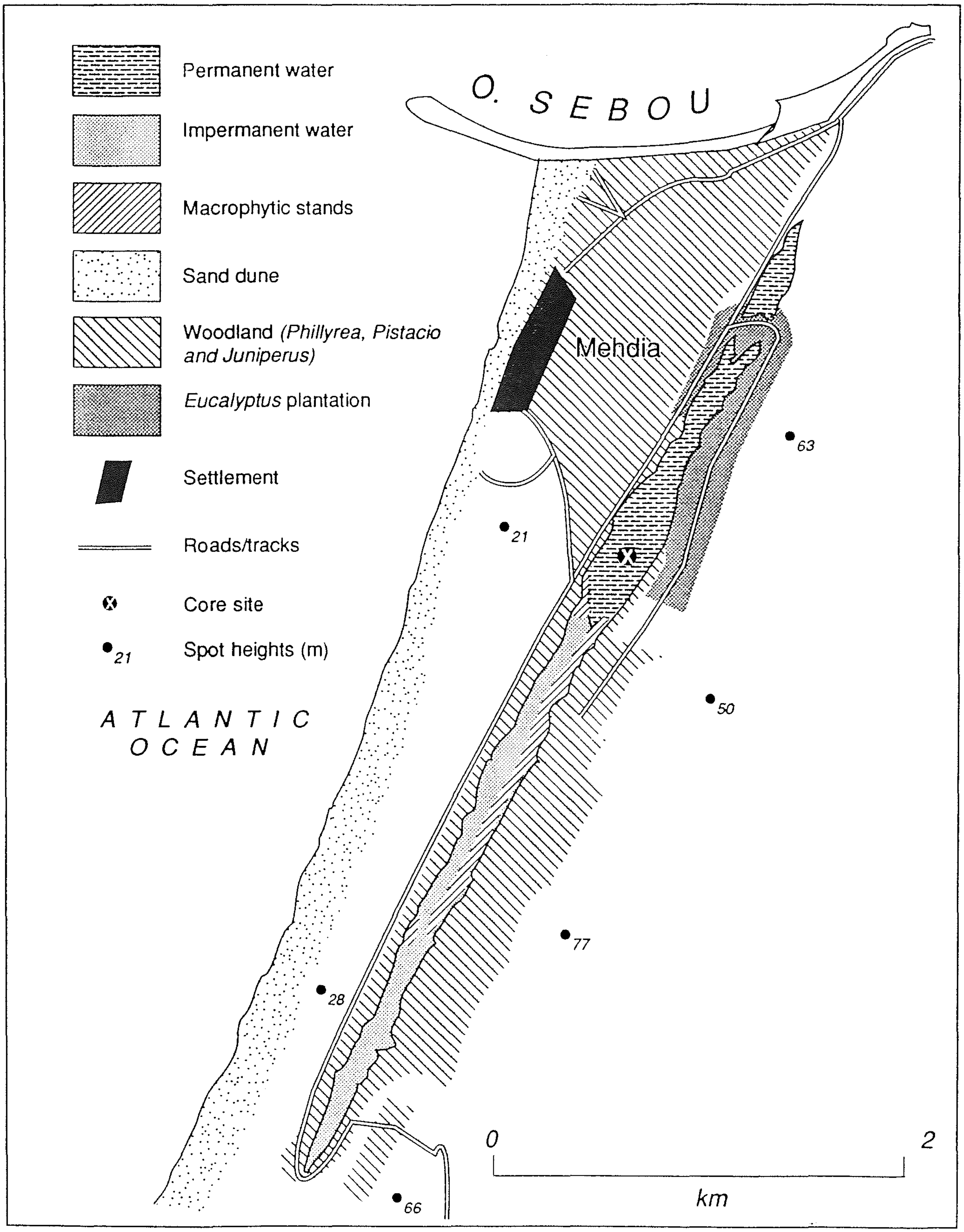


Figure 3 Merja Zerga: site map

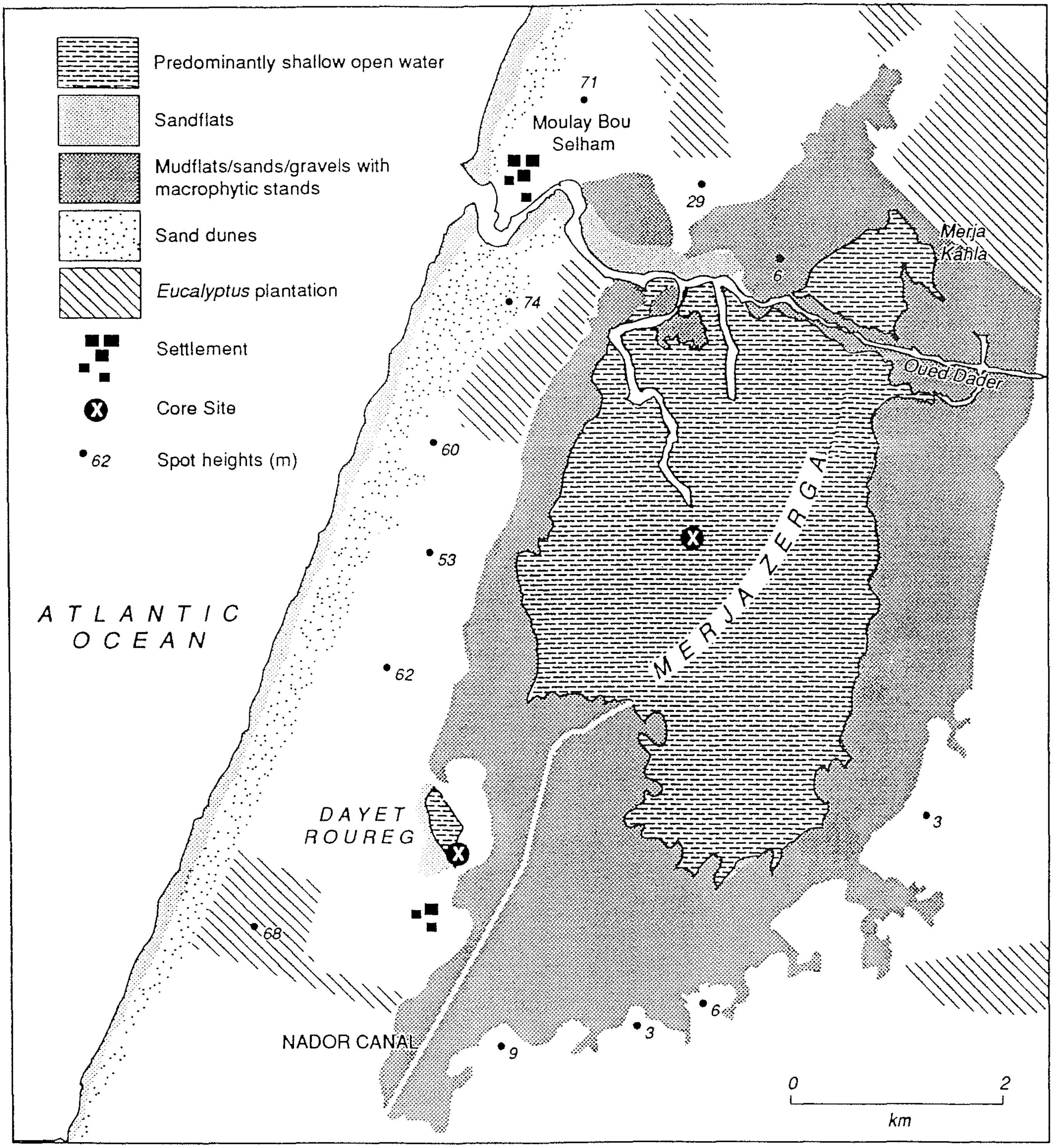
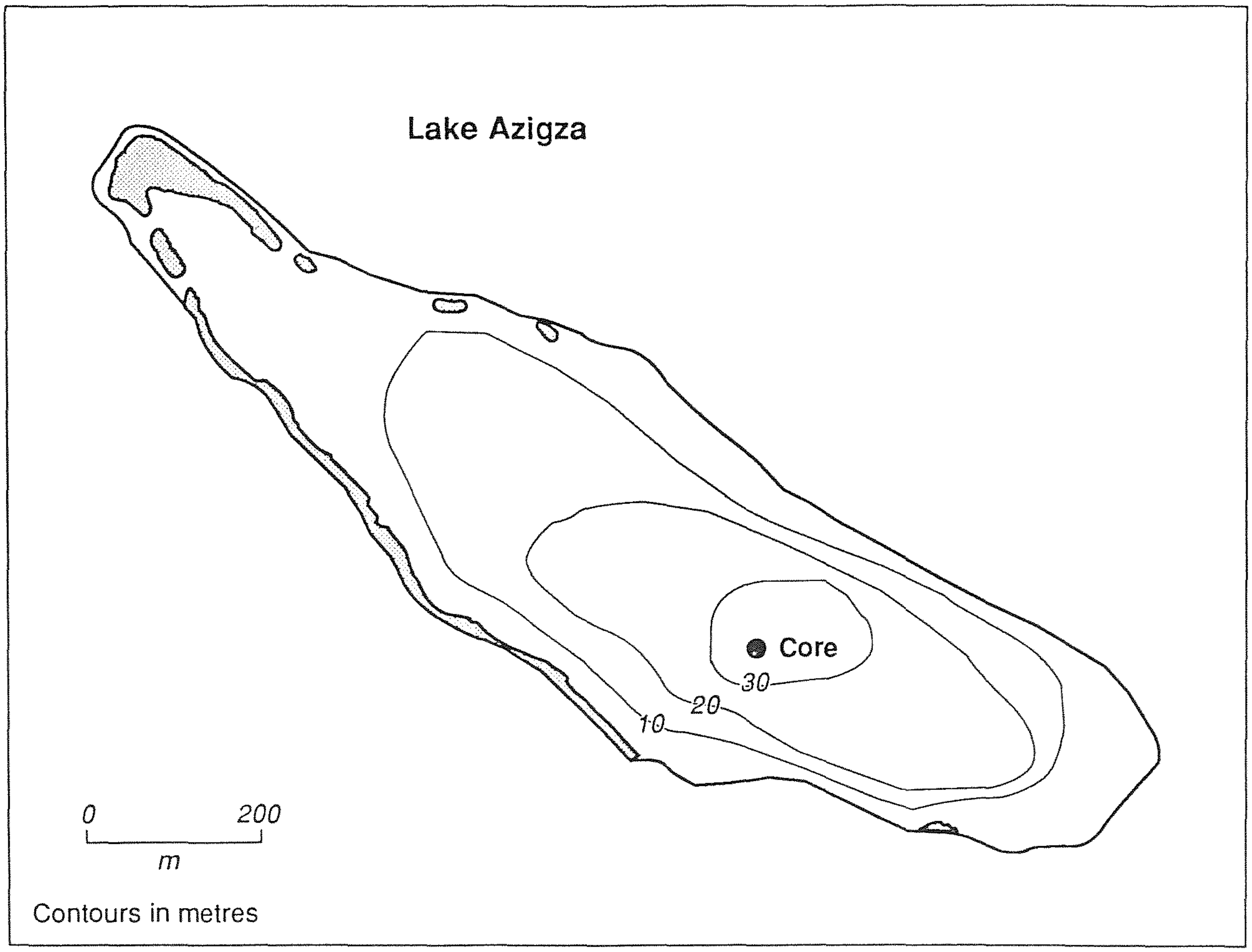


Figure 4 Lac Azigza: bathymetry



3. FIELD SAMPLING

Sediment cores were collected from each site in July 1990 using different techniques. A modified Livingstone corer operated from an inflatable boat was used to collect a 1.20 m long core from the deepest point (1.4 m) in Sidi bou Rhaba. Coring in the centre of the Merja Zerga was unsuccessful with equipment then available. A 1 m long core was collected from Dayet Roureg, a small lagoon at the south-western edge of the Merja (Figure 3) where sediments were more amenable to coring, using a Livingstone corer. A short, 12 cm long, core was collected from 31 m depth in Lac Azigza using a gravity corer operated from an inflatable boat.

Water samples were collected from each site in one litre polypropylene bottles.

4. METHODS

Cores were extruded and sectioned at 1 cm intervals in the laboratory. Sub-samples were used to determine wet density, percentage dry weight, and loss on ignition (LOI) at 550°C and 950°C according to the methods described in Stevenson *et al.* (1987). LOI at 550°C provides an estimate of sediment organic content and at 950°C of carbon dioxide loss (as the carbonates in the sediment decompose). The proportion of carbonate (as calcium carbonate) can be then calculated according to Dean (1974).

Radiometric dating of two sediment cores, from Sidi bou Rhaba and Lac Azigza, was undertaken by radioisotope assay using gamma spectrometry (Appleby *et al.* 1986).

Preliminary diatom analysis involved counting 300 valves per sample where possible. One core (Lac Azigza) was analysed in detail. Species present were identified using standard floras and samples were prepared using methods described in Battarbee (1986).

Carbonaceous particle analysis from the Sidi bou Rhaba sediment core was undertaken according to the methods of Rose (1990).

Water chemistry determinations were made at the University of Ulster Freshwater Laboratory according to standard techniques.

5. RESULTS

Water chemistry

Table 2 shows that all sites possess strongly alkaline, high pH waters. Sodium, magnesium and calcium are the most common cations at these sites but their concentrations are very different. Sidi bou Rhaba and the Merja are saline lakes having salinities above $3^0/_{00}$. The Merja, being connected directly to the sea, is a brackish water lagoon with a widely fluctuating salinity which was around $16^0/_{00}$ at the time of sampling. Chloride is the most common anion at the former site and probably also in the latter. The upland lake, Lac Azigza, is relatively dilute and being far from contemporary marine influences has low conductivity; calcium and bicarbonate are the most common ions. Water transparency was also very different at the three sites, being low at the two coastal sites. When sampling took place Sidi bou Rhaba contained a very high density of phytoplankton, mainly represented by the spiralled blue green *Laevissima*. Phytoplankton density was low in the open water of the Merja and the high turbidity resulted from sediment re-suspended by tidal currents. Lac Azigza is a clear water lake with a small turbidity component from phytoplankton.

Table 2. **Water quality data for the three sites as measured in July 1990. Figures in parenthesis refer to the range of concentration measured in 1979 (from Ramdani 1981), salinity ranges are from Beaubrun (1976).**

		Sidi bou Rhaba	Merja Zerga	Dayat Roureg	Lac Azigza
pH		8.0	-	-	8.5
Conductivity	$\mu S\ cm^{-1}$	15340	48700	31200	416
Alkalinity	meq l^{-1}	9.7 (3.3-9.0)	-	4.91	4.16
Salinity	$^0/_{00}$	5	16	-	-
Salinity	range ($^0/_{00}$)	3-12	35-<5	-	-
Ca	mg l^{-1}	74 (30-80)	-	-	24
Mg	mg l^{-1}	289 (100-300)	1614	926	42
Na	mg l^{-1}	2660	6080	6250	53
K	mg l^{-1}	74	530	338	0.5
SO_4	mg l^{-1}	1864	-	-	12
Cl	mg l^{-1}	2710 (2000-6000)	-	-	34
Sechi disc	m	0.2*	0.4*	-	7.0

* Low water transparency measured at the coastal sites was largely due to a dense phytoplankton crop at Sidi bou Rhaba and a high suspended silt load at the Merja Zerga.

\- not measured/not applicable

Sidi bou Rhaba

Sediment description

The entire 1.2 m core consisted of light grey sediment with the top 10 cm or so being rather more flocculant in appearance than that below. Examination of the fresh sediment showed that it was composed of amorphous aggregates with abundant remains of aquatic organisms, particularly large diatom algae. Also noteworthy was that several species of blue-green, especially *Microcystis* colonies, and green algae were well preserved down to about 20 cm depth in the sediment. These un-silicified algae normally decompose rapidly on sedimentation and their presence indicates either frequent re-suspension of the top 20 cm of sediment, a very high sediment accumulation rate, or unusually effective preservation characteristics of the sediment.

The lithostratigraphic characteristics of the core (Figure 5) show that measurements of wet density and percentage dry weight remain essentially constant throughout the core. Percentage dry weight declines from 4% at the sediment surface to about 15% below 18 cm depth, reflecting sediment disturbance or compaction effects. Below 18 cm, percentage dry weight increases very slightly with depth. The organic matter profile is fairly constant at around 30% with a small increase near the core base, at about 108 cm, and is associated with a layer of macrophyte remains (probably *Ruppia*). The profile of weight loss at 950°C shows a small decline around 108 cm depth followed by a small peak at 105 cm. A more sustained trend from about 65 cm occurs, from where CO_2 loss increases from 16% to 30% at the core top.

Sediment dating.

Sediment samples from the Sidi bou Rhaba core were analysed for ^{210}Pb, ^{226}Ra, (Table 3) ^{137}Cs and ^{241}Am (Table 4) by gamma spectrometry using a well-type coaxial background intrinsic germanium detector fitted with a NaI(TL) escape suppression shield (Appleby *et al.* 1986).

^{210}Pb-derived depth versus age relationships calculated using the CRS and CIC ^{210}Pb dating models (Appleby & Oldfield 1978) are shown in Figure 6. Significant differences between the two chronologies occur as a consequence of non-monotonic features on the unsupported ^{210}Pb profile. The CRS model attributes these features to episodes of accelerated sedimentation, with an earlier such episode dating from the mid-1970s. Non-monotonic features are not consistent with the basic principles of the CIC model and are attributed to reworking of older sediments.

The ^{137}Cs activity in the core has a well defined peak at between 53.5 and 62.5 cm (Table 4), which clearly dates these levels to the period of maximum fallout from the atmospheric testing of nuclear weapons in the early 1960s. This inference is supported by the presence of a small peak in ^{241}Am activity at the same level. The fallout record of ^{241}Pu, the source of this radionuclide parallels that of the ^{137}Cs (Appleby *et al.* 1991). The ^{137}Cs date plotted in Figure 6 along with the ^{210}Pb dates, is in reasonable agreement with the CRS model. The level at which ^{137}Cs and ^{241}Am both have their maximum values, 53.5 cm, has a CRS model ^{210}Pb date of 1962. The estimated 1963 level of 57.5 cm, determined from the shape of the fallout profiles, is dated 1958. Agreement with the CIC model is less satisfactory. This model dates the peak fallout levels to the early 1970s, although exact comparisons are difficult because of the irregularity of the CIC dates.

In view of the relatively good agreement with the ^{137}Cs record, the chronology given in Table 5 has been based principally on the CRS model. The results show that during the period 1900 - 1970 there was a more or less constant sedimentation rate of c. 0.169 g cm^{-2} yr^{-1}, interrupted only by a brief episode of accelerated sedimentation dated to 1947. During the past 20 years, however, there has been a more sustained disturbance and the mean sedimentation rate for this period increased by about 35% to c. 0.23 g cm^{-2} yr^{-1}.

Table 3 Sidi bou Rhaba: ^{210}Pb data

Depth	Dry mass	^{210}Pb Conc.				^{226}Ra Conc.	
		Total		Unsupp.			
cm	g cm^{-2}	pCi g^{-1}	±	pCi g^{-1}	±	pCi g^{-1}	±
0.50	0.0187	2.14	0.43	1.81	0.45	0.33	0.13
1.50	0.0661	3.08	0.22	2.73	0.23	0.35	0.06
10.50	0.8240	2.92	0.15	2.53	0.16	0.39	0.05
20.50	1.9471	2.21	0.16	1.82	0.17	0.39	0.05
32.50	3.3485	2.04	0.13	1.57	0.14	0.47	0.05
42.50	4.5681	2.26	0.15	1.88	0.16	0.38	0.05
53.50	5.9671	2.04	0.13	1.57	0.14	0.47	0.05
62.50	7.2348	1.88	0.13	1.50	0.14	0.38	0.04
69.50	8.2358	1.14	0.14	0.68	0.15	0.46	0.05
81.50	9.9699	1.29	0.16	0.82	0.17	0.47	0.05
100.50	12.7993	0.95	0.11	0.40	0.12	0.55	0.05
114.50	15.1568	0.79	0.12	0.29	0.13	0.50	0.04

Unsupported ^{210}Pb inventory = 19.7±0.8 pCi cm^{-2}
^{210}Pb flux = 0.61±0.03 pCi cm^{-2} yr^{-1}

Table 4 Sidi bou Rhaba: ^{137}Cs and ^{241}Am data

Depth	^{137}Cs Conc.		^{214}Am Conc.	
cm	pCi g^{-1}	±	pCi g^{-1}	±
0.50	0.73	0.08	0.00	0.00
1.50	0.76	0.07	0.00	0.00
10.50	0.86	0.04	0.00	0.00
20.50	1.25	0.05	0.00	0.00
32.50	1.45	0.04	0.00	0.00
42.50	1.50	0.05	0.00	0.00
53.50	2.18	0.05	0.05	0.01
62.50	2.03	0.05	0.02	0.01
69.50	0.87	0.03	0.03	0.01
81.50	0.18	0.03	0.00	0.00
100.50	0.14	0.03	0.00	0.00
114.50	0.03	0.03	0.00	0.00

^{137}Cs Inventory = 13.8±0.8 pCi cm-2
^{241}Am Inventory = 0.13±0.02 pCi cm^{-2}

Table 5 Sidi bou Rhaba: ^{210}Pb Chronology

Depth	Cum. dry mass	Chronology			Sedimentation rate		
		Date	Age				
cm	g cm^{-2}	AD	yr	±	g cm^{-2} yr^{-1}	cm yr^{-1}	± (%)
0.00	0.0000	1990	0				
2.50	0.1503	1989	1	2	0.2221	2.703	9.5
5.00	0.3608	1988	2	2	0.2202	2.540	9.1
7.50	0.5714	1987	3	2	0.2183	2.377	8.8
10.00	0.7819	1987	3	2	0.2164	2.214	8.4
12.50	1.0486	1985	5	2	0.2246	2.197	8.8
15.00	1.3294	1984	6	2	0.2353	2.215	9.5
17.50	1.6102	1983	7	2	0.2460	2.233	10.1
20.00	1.8909	1982	8	2	0.2567	2.252	10.7
22.50	2.1807	1981	9	2	0.2578	2.233	10.9
25.00	2.4726	1979	11	2	0.2566	2.206	11.0
24.50	2.7649	1978	12	2	0.2554	2.178	11.1
30.00	3.0565	1977	13	2	0.2542	2.151	11.2
32.50	3.3485	1976	14	2	0.2529	2.123	11.3
35.00	3.6534	1975	15	2	0.2338	1.946	11.4
37.50	3.9583	1973	17	2	0.2147	1.769	11.5
40.00	4.2632	1972	18	2	0.1955	1.592	11.6
42.50	4.5681	1970	20	2	0.1764	1.415	11.7
45.00	4.8861	1968	22	2	0.1735	1.372	12.2
47.50	5.2040	1967	23	2	0.1705	1.329	12.7
50.00	5.5220	1965	25	3	0.1676	1.286	13.1
52.50	5.8399	1963	27	3	0.1646	1.243	13.6
55.00	6.1784	1961	29	3	0.1580	1.175	14.3
57.50	6.5305	1958	32	3	0.1489	1.091	15.1
60.00	6.8827	1956	34	4	0.1398	1.006	15.9
62.50	7.2348	1953	37	4	0.1307	0.922	16.7
65.00	7.5923	1951	39	4	0.1696	1.187	20.0
67.50	7.9498	1949	41	4	0.2086	1.453	23.3
70.00	8.3081	1947	43	5	0.2360	1.638	25.9
72.50	8.6693	1945	45	5	0.2172	1.503	25.7
75.00	9.0306	1943	47	5	0.1984	1.368	25.5
80.00	9.7531	1939	51	6	0.1608	1.097	25.1
85.00	10.4911	1935	55	7	0.1541	1.033	27.9
90.00	11.2357	1930	60	8	0.1605	1.057	31.9
95.00	11.9803	1925	65	9	0.1670	1.081	35.9
100.00	12.7248	1921	69	10	0.1734	1.105	40.0
105.00	13.5571	1916	74	12	0.1674	1.045	43.3
112.00	14.8200	1908	82	15	0.1564	0.942	48.1

Diatom analysis

The diatom assemblage in this 116 cm core was dominated throughout by several species, *Campylodiscus clypeus* being most abundant. SEM photographs of *C. clypeus* are shown in Plate 1. Other common species present were *Achnanthes marina, Cyclotella meneghinina, Cymbella pusilla, Cocconeis placentula, Navicula cruciculoides* and *Plagiotropis (= Tropidoneis) lepidoptera*. Most diatoms were well preserved throughout the core, however it was noted that drying of the sediment before diatom analysis caused the larger diatom, *C. clypeus,* to break up.

Detailed diatom analysis of this core has not yet been carried out but some changes in percentage abundances of common taxa do occur in some sections of the core. The percentage frequencies of diatom taxa in the surface sediment are given in Table 6.

Carbonaceous particle analysis

The surface 40 cm (1972-1990) of sediment have been analysed for carbonaceous particles (Rose 1990). The results portrayed in Figure 7 indicate that this site is significantly affected by atmospheric pollution, at least in the recent past.

Table 6 **Percentage frequencies of diatom taxa in the surface sediment (0.0-1.0 cm depth) from Sidi bou Rhaba.**

Taxon	Percentage abundance
Campylodiscus clypeus v. *clypeus*	26.6
Achnanthes marina	11.3
Navicula cruciculoides	8.9
Cocconeis placentula	8.9
Cyclotella meneghiniana	8.0
Cymbella pusilla	6.5
Amphora subcapitata	4.8
Anomoeoneis sculpta	4.8
Fragilaria brevistriata	4.0
Mastogloia brauni	3.2
Navicula capitata v. *hungarica*	2.4
Amphora commutata	2.4
Amphora cf. *mexicana*	2.4
Fragilaria virescens v. *subsalina*	<1
Navicula tenelloides	<1
Navicula subrhyncocephala	<1
Surirella ovalis	<1
Synedra cf. *tenera*	<1
Tropidoneis lepidoptera	<1

Note: *A. sculpta* appears to be a large form of *A. spheārophora*

Figure 5 **Sidi bou Rhaba: lithostratigraphy**

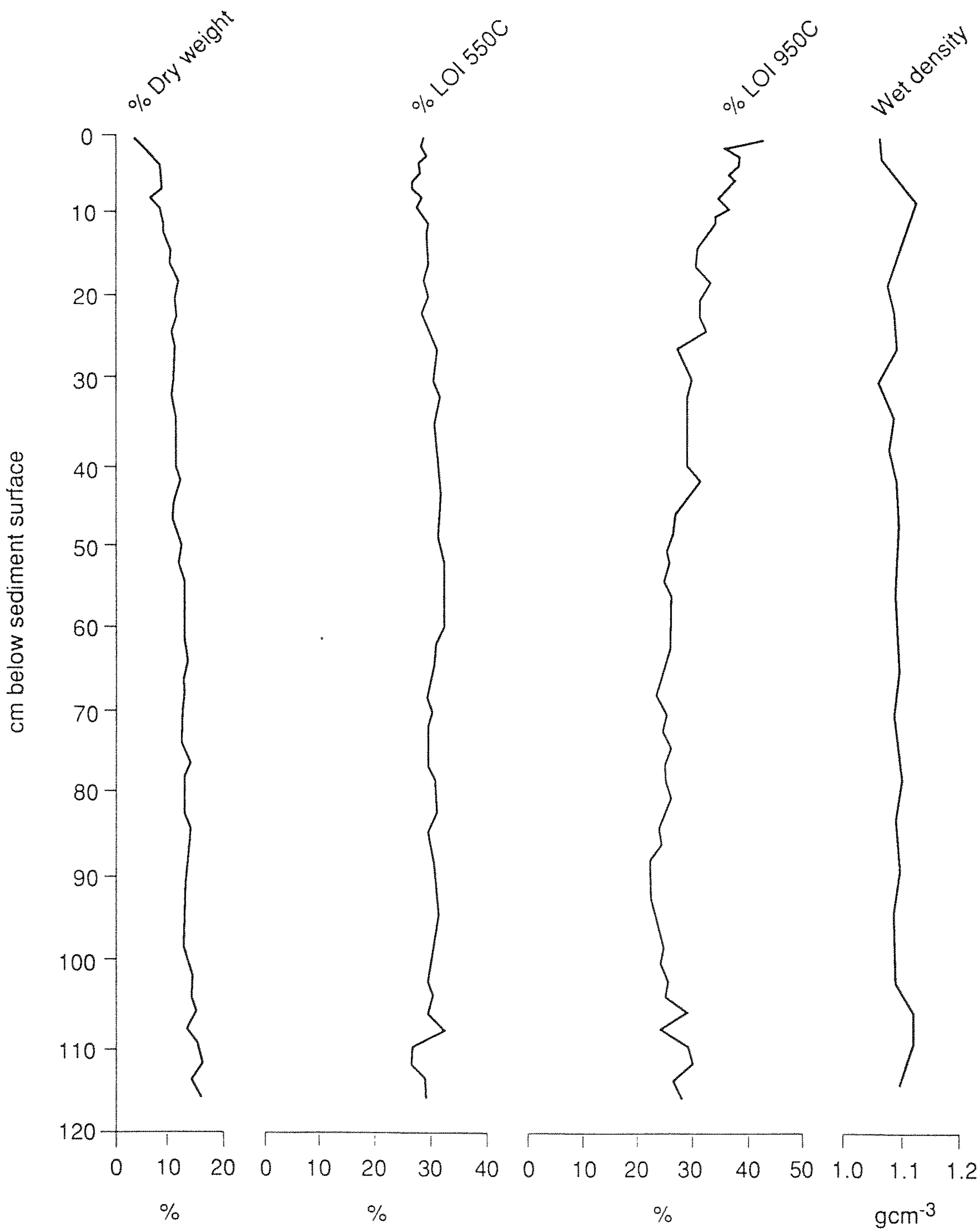


Figure 6 Sidi bou Rhaba: ^{210}Pb chronology

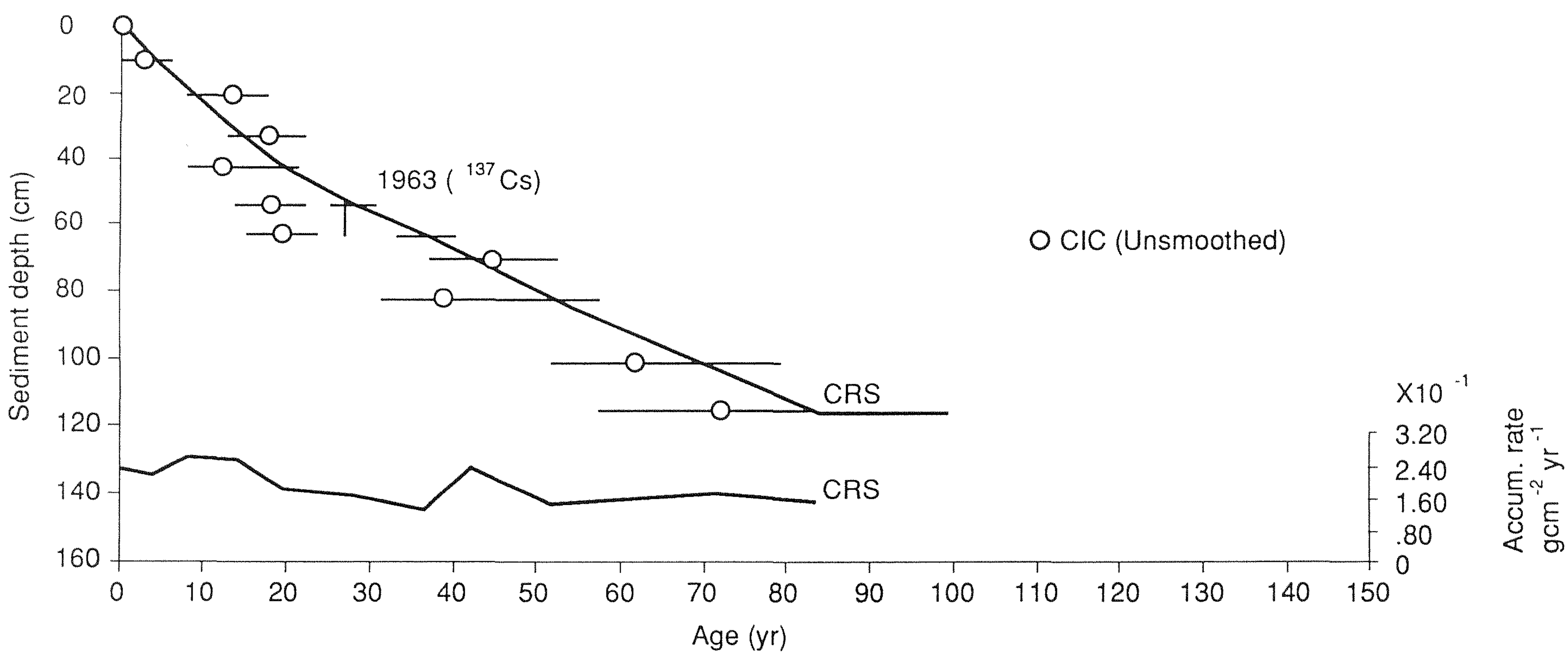


Plate 1 Scanning electron microscope photographs of *Campylodiscus clypeus* in sediment from Sidi bou Rhaba. 1. & 2.; external and internal views, note the saddle shape of the valve and the raised rhaphe canal around the periphery of the valve. 3.; detail of the internal structure of the marginal area showing the costae, internal apertures of the raphe canal and the fibulae. 4., 5., & 6.; detail of small diatoms living epiphytically on the surface of *C. clypeus*, the first two photographs show the epiphyte *Achnanthes marina* and the latter shows a *Navicula*, probably *N. elkab.*

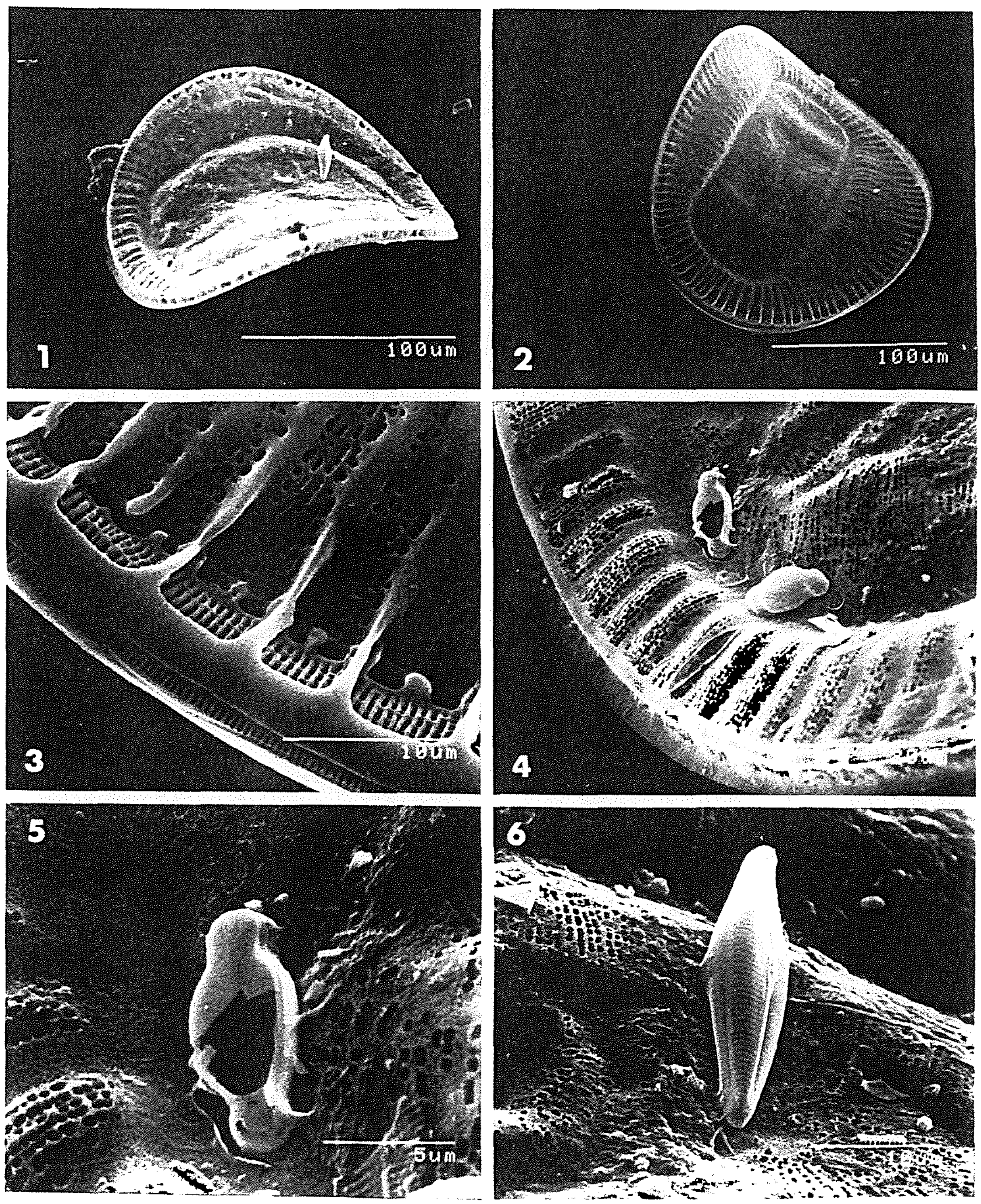
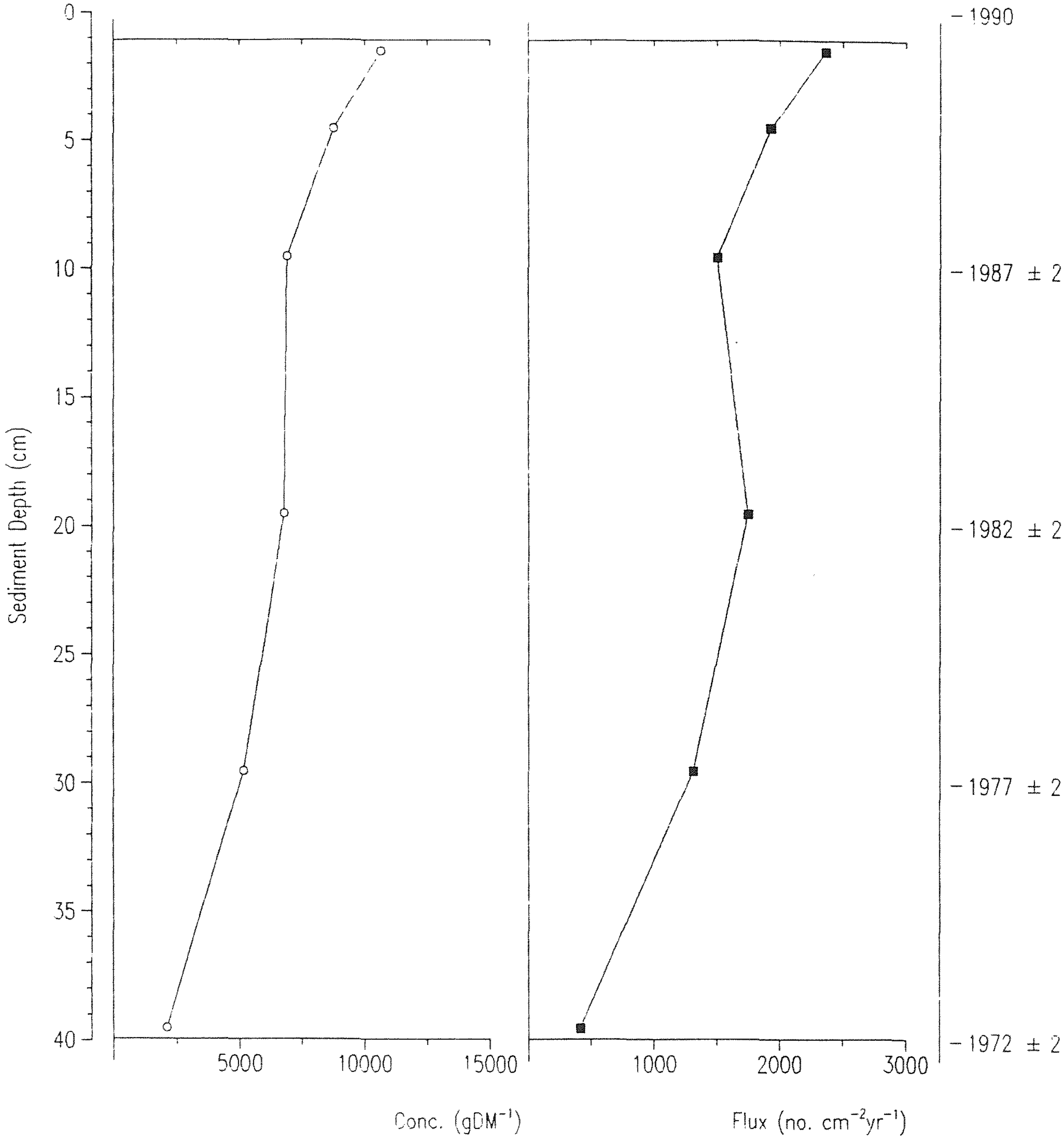


Figure 7 **Sidi bou Rhaba: carbonaceous particle concentration and flux profiles**



Merja Zerga

Central basin

Surface sediment in the main part of the Merja consisted of cohesive clays and silts with abundant mollusc shell remains. The sediment was much coarser in the deeper drainage channels and consisted of small stones and *Cerastoderma* shells and was unsuitable for coring with the available equipment. A surface sediment sample was retrieved and the common diatom taxa present are shown in Table 7. The diatom flora was represented by an assemblage of rather broken diatom valves and was strongly dominated by *Cocconeis placentula*.

Table 7 **Percentage frequencies of diatom taxa in the surface sediment (0.0-1.0 cm depth) of the central basin of the Merja Zerga**

Taxon	Percentage abundance
Cocconeis placentula	66.5
Cocconeis scutellum	8.8
Nitzschia cf. *frustulum*	4.4
Pleurosigma elongatum	3.3
Amphora coffeaeformis	2.2
Navicula elkab	<1
Synedra tabulata	<1
Navicula sp.	<1
Amphora sp.	<1

Dayat Roureg

The 1 m long sediment core retrieved from Dayat Roureg was used for lithostratigraphic analysis. The top 5 cm consisted of reddish silts and clays below which the sediment became more greyish in colour. Below about 20 cm depth the sediment was darker with increasing amounts of plant remains present. By 50 cm the sediment was black. The very basal 3 cm of the core returned to grey clay.

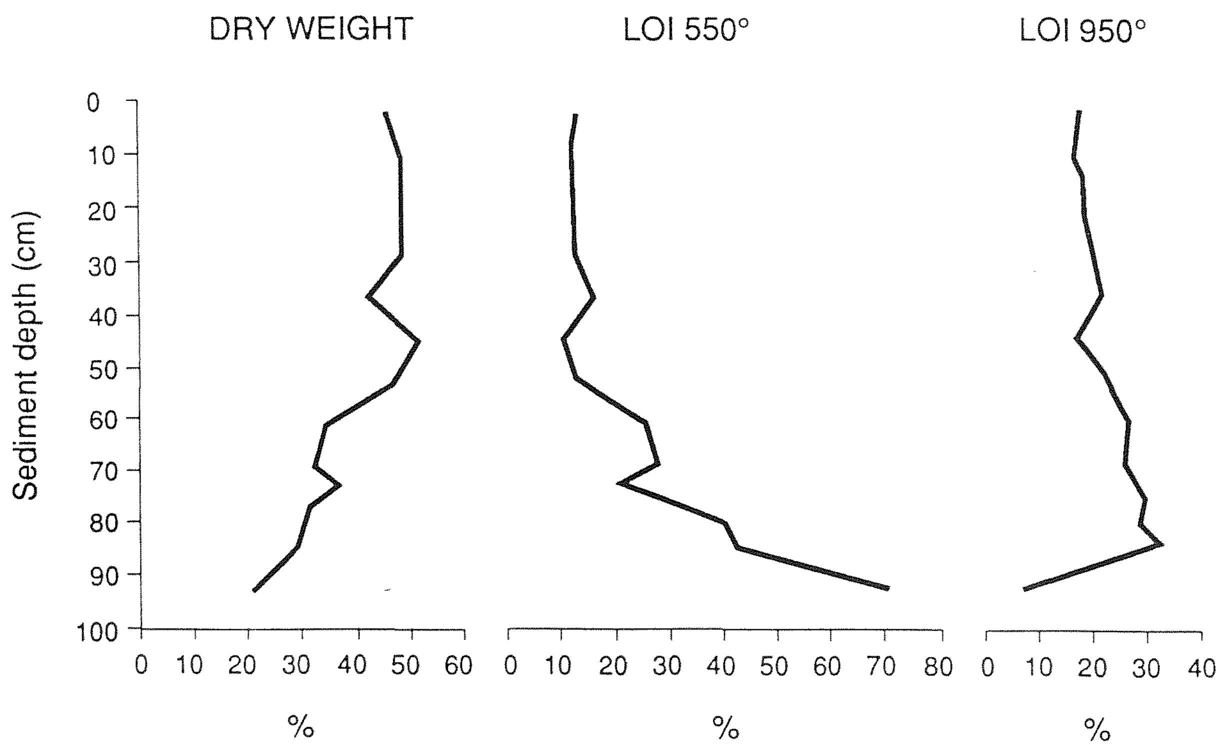
The wet density and percentage dry weight profiles for the core (Figure 8) show major changes with depth in the sediment. The upper portion of the core is composed of clays and has high wet density and percentage dry weight values. Towards the base of the core the percentage organic matter (LOI at 550°C) increases markedly as percentage dry weight and sediment wet density decline. The sediment becomes more minerogenic again in the bottom 10 cm.

The Dayet Roureg core has not yet been dated or analysed stratigraphically for diatoms. However, percentage frequencies of diatom taxa in surface sediment (0.0-1.0 cm depth) from this core were determined (Table 8). The diatom flora was represented by a diverse assemblage of taxa with *Entomoneis (= Amphiprora) alata* being the most abundant. This epipelic species was actively growing on the surface of the sediment at the time of sampling.

Table 8 Percentage frequencies of diatom taxa in the surface sediment (0.0-1.0 cm depth) of Dayet Roureg

Taxon	Percentage abundance
Entomoneis alta	16.9
Anomoeoneis sculpta	12.7
Amphora subcapitata	8.6
Navicula elkab	8.6
Navicula pygmaea	7.0
Amphora veneta	7.0
Amphora coffeaeformis	5.6
Navicula halophila	4.2
Navicula gracilis	4.2
Navicula salinarum	4.2
Nitzschia apiculatum	4.0
Navicula cinta	2.8
Cocconeis placentula	2.8
Campylodiscus clypeus	<1
Achnanthes beviceps	<1
Pleurosigma elongatum	<1
Navicula phyllepta	<1
Plagiotropis lepidoptera	<1
Navicula sp. 1	<1
Stauroneis sp. 1	<1

Figure 8 Dayat Roureg: Lithostratigraphy



Lac Azigza

Sediment description

The top 2 cm of the 11.5 cm long core taken from 32 m of water (Figure 4) in this lake were black, whereas the remaining 9 cm were of a uniform grey colour; several chironomid tubes were noted on the surface sediment.

Lithostratigraphic analysis of the core (Figure 9) showed small changes in sediment compaction and composition. Both sediment wet density and percentage dry weight declined from above about 6 cm (1978) depth, the latter declining from around 30 to 20%. Organic matter was low throughout the core but increased from 7% at 5.5 cm (1979) to over 12% at the core top (1991). As indicated by CO_2 loss at 950°C, carbonates were generally high throughout the core but showed a decreasing trend above 6 cm depth, where LOI declines from about 20% to 16% at the core top. This decline approximately corresponds to the increase in organic matter.

Sediment dating

Sediment from the top 12 cm of the Lac Azigza core were analysed for ^{210}Pb, ^{226}Ra, (Table 9) and ^{137}Cs (Table 10). The ^{210}Pb results (Table 9) show that the basal sample at 11-12 cm contains relatively high levels of unsupported ^{210}Pb and thus must be relatively recent in origin. This is confirmed by the ^{137}Cs results (Table 10). Since the maximum ^{137}Cs activity occurs in the 11-12 cm sample, it may be inferred that all the sediment above this level post-date the 1963 peak in fallout from atmospheric testing of nuclear weapons.

Because of the incomplete ^{210}Pb record, standard procedures for calculating dates using the CRS ^{210}Pb dating models (Appleby & Oldfield 1978) are not applicable. Use of the CIC dating model over relatively short sequences of near surface sediments is also inadvisable due to the susceptibility of this model to errors arising from possible mixing of the surface sediments. A comparison of the ^{137}Cs record with that from a core retrieved in 1984 (Flower *et al.* 1988) suggests that the date of the base of the core at 12 cm must be close to 1963. Using this as a reference level, CRS ^{210}Pb dates can be constructed using the methods described in Oldfield & Appleby (1984). Dates calculated in this way are given in Table 11.

The ^{137}Cs dates give a mean sedimentation rate for the past 27 years of c. 0.18 g cm^{-2} yr^{-1}. The CRS model calculations do not indicate any major departures from this figure, although they do suggest higher values in the period 1976-1984. This is consistent with the results from the 1984 core (Flower *et al.* 1988) which showed a maximum sedimentation rate of c. 0.19 g cm^{-2} yr^{-1} in 1983. The enhanced ^{210}Pb concentrations in the near-surface sediments of the 1990 core may indicate a small decline in the sedimentation rate from the 1983 peak value over the past few years.

Table 9 Lac Azigza: ^{210}Pb data

Depth	Dry mass	^{210}Pb Conc.				^{226}Ra Conc.	
		Total		Unsupp.			
cm	g cm^{-2}	pCi g^{-1}	±	pCi g^{-1}	±	pCi g^{-1}	±
0.25	0.058	6.36	0.44	4.95	0.45	1.41	0.11
1.75	0.492	4.81	0.28	3.64	0.29	1.17	0.06
3.75	1.175	3.85	0.24	2.52	0.25	1.33	0.07
6.50	2.365	3.36	0.26	2.43	0.26	0.93	0.05
9.50	3.753	3.19	0.18	2.23	0.19	0.96	0.05
1.50	4.664	3.18	0.24	2.08	0.25	1.10	0.06

Table 10 Lac Azigza: ^{137}Cs data

Depth	^{137}Cs Conc.	
cm	pCi g^{-1}	±
0.25	2.75	0.11
1.75	2.23	0.06
3.75	2.21	0.06
6.50	2.84	0.07
9.50	5.35	0.08
11.50	6.17	0.09

Table 11 Lac Azigza: ^{210}Pb chronology

Depth	Cum. dry mass	Chronology			Sedimentation rate		
		Date	Age				
cm	g cm^{-2}	AD	yr	±	g cm^{-2} yr^{-1}	cm yr^{-1}	± (%)
0.00	0.00	1990	0				
1.00	0.27	1988	2	2	0.16	0.52	8.5
2.00	0.58	1986	4	2	0.18	0.55	8.1
3.00	0.92	1985	5	2	0.21	0.56	8.9
4.00	1.28	1983	7	2	0.22	0.56	9.5
5.00	1.72	1981	9	2	0.22	0.51	9.6
6.00	2.15	1979	11	2	0.20	0.46	9.7
7.00	2.60	1976	14	2	0.19	0.43	9.4
8.00	3.06	1974	16	2	0.18	0.40	8.8
9.00	3.52	1971	19	2	0.17	0.38	8.2
10.00	3.98	1969	21	2	0.16	0.36	7.8
11.00	4.44	1966	24	2	0.16	0.34	7.5

Diatom analysis

High resolution diatom analysis of the entire 11.5 cm long core was carried out and the frequency abundances of the common taxa are shown in Figure 10. The diatom assemblage throughout the core is dominated by planktonic *Cyclotella* taxa which show strong changes in frequency abundances. *C. azigzensis* declines throughout the core from almost 40% abundance at the base (1964) to <5% in the top 0.5 cm (1990) of sediment. Over the same section *C. ocellata* increases strongly, from <5% to over 80% frequency abundance at the core top. *Cyclotella [nopunctata]* is a small taxon (<10 μm in diameter) with no central processes but having a marginal structure similar to *C. ocellata*. Abundance of this taxon together with that of *C. comensis* declines above 6 cm depth (1978).

Comparison of the diatom record in this short core taken in 1990 with that in a longer core from Lac Azigza taken in 1984 is difficult for several reasons. Firstly, the earlier core was sampled at much coarser intervals of 10 cm compared with 0.5 cm intervals in the 1990 core. Secondly and more importantly, taxonomic concepts have changed with regard to several important *Cyclotella* taxa; *C. ocellata*, *C azigzensis* (a new taxon described by Flower *et al.* 1988) and *C. [nopunctata]* have largely replaced the old *C. kutzingiana* 'group' used in the 1984 core. This earlier core does however provide evidence of a post-1960s decline in *C. azigzensis* (Flower *et al.* 1988).

In addition to the 1990 core, several samples of diatom epiphyton were also collected from *Ranunculus* growing at about 3 m depth at the western end of the lake. Diatom analysis of one sample was undertaken by J.R. Carter and the resulting species list is given in Appendix 1.

Figure 9 **Lac Azigza: lithostratigraphy**

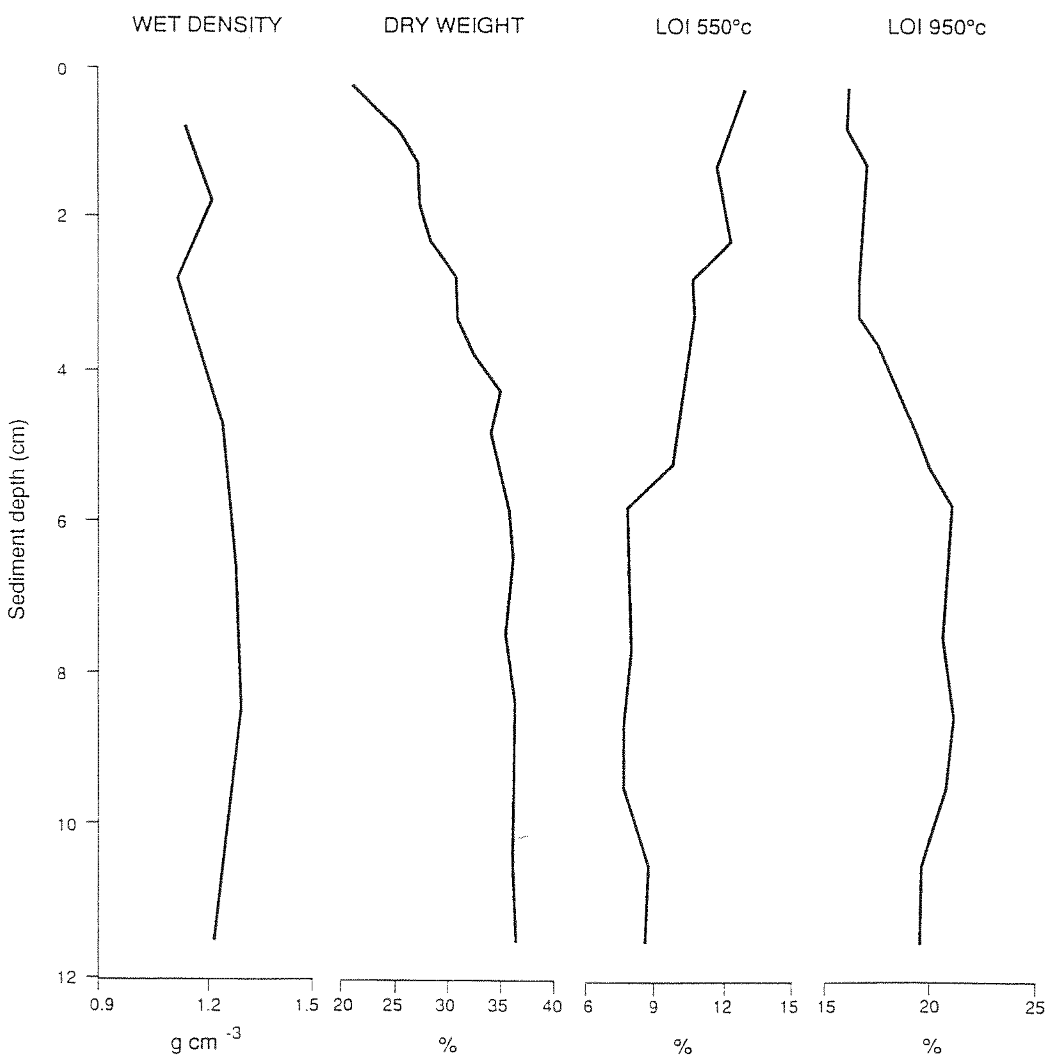
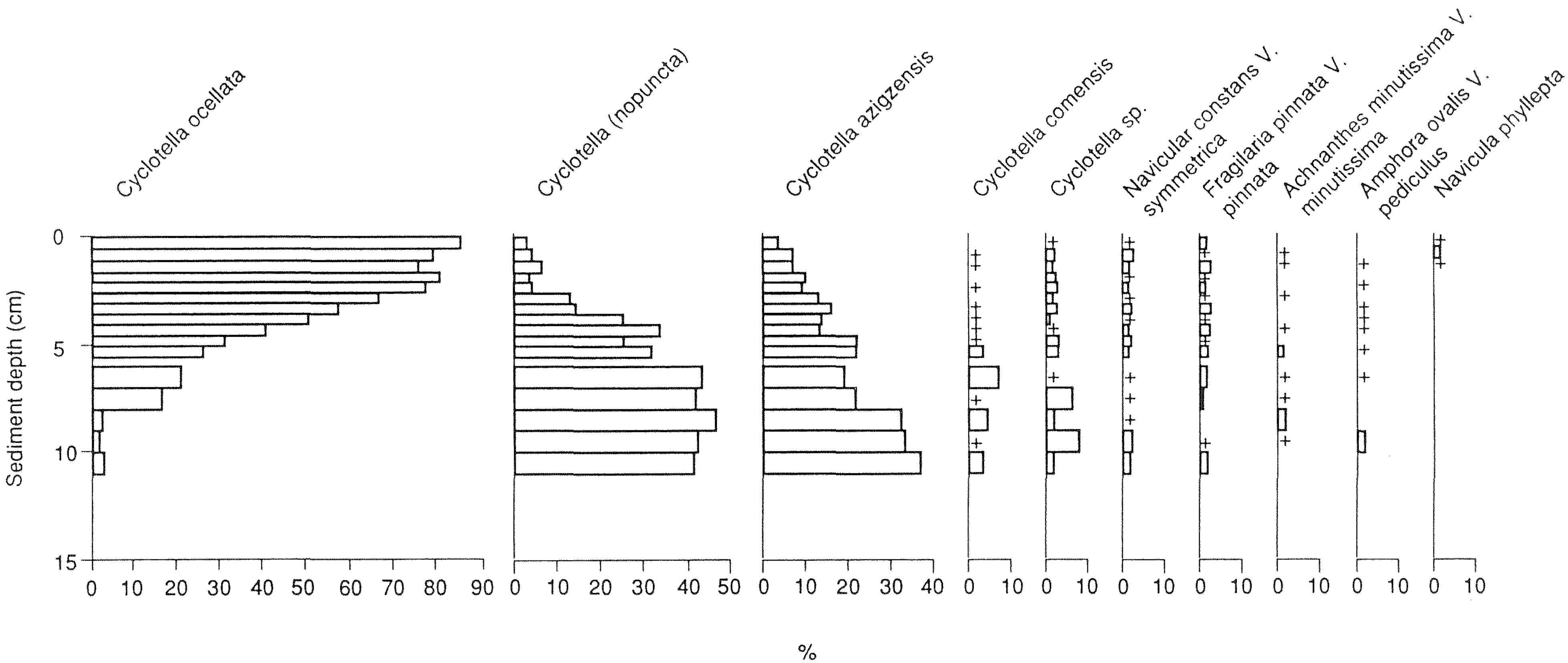


Figure 10 Lac Azigza: summary diatom diagram



6. DISCUSSION

The saline coastal sites and upland Lac Azigza are all disturbed to varying degrees by environmental changes that have occurred during this century. Although ecological trends have only been assessed by diatom analysis for one site (Lac Azigza), changes in gross sediment type and accumulation rate indicate that sediment accumulation rates have increased at all three sites.

The sediment accumulation rate is currently very high in Sidi bou Rhaba at over 2 cm yr^{-1}. In terms of dry weight of sediment accumulated peak values occurred around 1981 and 1947 and seem to be associated with small decreases in sedimentary carbonates and could indicate small pulses of soil erosion. The bulk of the sediment is however autochthonous, being composed of precipitated salts and biogenic material. Soil erosion from the catchment into this lake is not a problem since there are no inflow streams and surrounding vegetation is generally well established. Diatom analysis of the surface sediment reveals a typical mesohalobous diatom flora dominated by *Campylodiscus clypeus*, a large diatom sometimes common in shallow saline lakes in North America. Without diatom analysis of the full core we do not yet know if the salinity of this site has changed substantially through time but macrophyte remains at the core base could indicate a period of low lake level. The high overall sediment accumulation rate indicates that the area of permanently open water will rapidly diminish in the near future. Already, approximately one third of the lake bed is dry in summer months and in approximately 50 years it is anticipated that this condition will extend to the entire lake area. An obvious consequence is that the site will become unsuitable for water birds for much of the year.

Little can be inferred about recent environmental change in the main basin of the Merja Zerga since coring was unsuccessful. Diatoms are shown to be present in surface sediment and the occurrence of *Cocconeis placentula* in abundance probably reflects its dominance as an epiphyte on *Zostera* rather than salinity levels *per se*. Despite the penetration of seawater to the Merja *C. placentula* is not generally regarded as a marine diatom. Rates of sediment accretion or erosion are as yet unknown and since the salinity regime of the Merja system is finely balanced between salt and freshwater inputs, the site offers considerable potential for investigating past changes in salinity.

The core from Dayat Roureg at the south-western edge of the Merja shows gross sedimentological changes which indicate major changes in the depositional environment at this site. Despite the absence of dating, these changes could be quite recent. Clays and silts, rich in mollusc shells and saline diatoms but low in organics, are deposited above a rich organic fen peat. Consequently, the swamp vegetation from which this lower section was derived is now lost. Such stratigraphic changes can be interpreted as a classic example of a marine transgression; increased penetration of seawater to the site being responsible for increased minerogenic sediment deposition. However, other processes could also account for this particular stratigraphic sequence; the implementation of land drainage, including the construction of the Nador Canal in the early 1950s, could also have brought about the observed sedimentary changes. In order to interpret the recent environmental history of the area further, information from microfossil analyses is required, followed by the statistical linkage of observed changes to stratigraphies of cores collected from elsewhere in the Merja system. However, preliminary results show unequivocally that Dayat Roureg has been highly disturbed and has suffered a loss of wetland vegetation indicating major landscape change. The modern lake therefore represents a degraded ecosystem, almost certainly with reduced bio-diversity and reduced value for wildfowl and other wildlife.

The upland lake, Lac Azigza, is a very different ecosystem from those supported at the lowland coastal sites, but its recent environmental history shares some similarities with these sites. As recorded at Sidi bou Rhaba and inferred for Dayat Roureg, the sediment accumulation rate in the Lac Azigza core, although relatively low, shows an increasing trend. This trend peaks in the early 1980s and corresponds to the maximum accumulation rate measured at the surface of an earlier and longer core from this site (Flower *et al.* 1988). The peak marks the end of a period of accelerated sediment accumulation which began by a sharp three-fold rate increase in the early part of this century. The lake level of Lac Azigza was low in the early 1950s and following a period of rising water level, subsequently declined by about 7 m between 1979 and 1984 and has remained stable since then (Flower & Foster 1992). There seems no direct link between sediment accumulation rate change and lake level change at this site. Hence the sedimentation rate changes are attributed to catchment disturbances and soil erosion. The site catchment is heavily used by people in the summer months and the area is intensely grazed. These activities have caused vegetation change and are probably responsible for increasing soil erosion into the lake.

With regard to ecosystem change, it is important to know if human pressures on Lac Azigza and its catchment have affected the lake biota and, if so, is the pressure increasing? The diatom record offers one way of assessing change over recent decades. The rapid increase in abundance of *C. ocellata* and decrease in *C. azigzensis* since the mid-1970s indicates that water quality has changed over this period. The change is probably related to nutrient supply but since the latter taxon is known from very few sites (Flower *et al.* 1988) its ecological optima are unknown. Both species are characteristic of oligotrophic hard water lakes and whatever water quality changes have occurred to bring about the shifts in species abundances they are probably small but nonetheless significant. If a large increase in nutrient supply occurred a *Stephanodiscus* or *Fragilaria* plankton might be expected to result. The diatom species changes seem to be unrelated to the inter-annual water level fluctuations documented for this lake. The complex and diverse diatom epiphyton (see Appendix 1) recorded here also suggests that the substantial changes in water level have not exerted any major long-lasting stress on littoral communities. The changes in sedimentary diatom assemblages recorded at Lac Azigza do have clear implications for nature conservation. The planktonic diatom flora is undergoing sustained change, the site is therefore ecologically unstable and, although biological changes over the past 15 years are as yet subtle, there is cause for concern about the future of this lake.

CONCLUSIONS

1) Steady-state conditions do not exist any of the sites investigated. Sediment dating reveals that the rate of sediment accumulation has increased at two sites, Sidi bou Rhaba and Lac Azigza. Changes in sediment stratigraphy indicate that a major change in sediment deposition has occurred at Dayat Roureg, a small saline lake at the south-western edge of the Merja Zerga. The carbonaceous particle record at Sidi bou Rhaba reveals strong evidence of atmospheric contamination in this coastal region.

2) The high rate of sediment accumulation measured in Sidi Bou Rhaba, a bird sanctuary and national nature reserve, indicates that the site will be seasonally dry within several decades. The acceleration in sediment accumulation is at least partly caused by increased deposition of carbonate minerals. Soil erosion does not seem to be a problem at this site.

3) In Dayat Roureg a rich fen peat is buried below some 50 cm of silts and clays. The siltation of wetland vegetation represents a major loss of habitat quality. Causes of the observed changes could include increased penetration by seawater and/or the effects of drainage projects in the early 1950s.

4) Sediment accumulation rate has increased at Lac Azigza, probably as a result of soil erosion. There is also a recent and sustained change in the percentage frequencies of the major species of planktonic diatoms in the sediment core. The change begins during the mid-1970s and indicates a small but ecologically significant change in water quality during the next 15 years. The change seems to be unrelated to inter-annual lake level fluctuations and increased human activity in the lake catchment is the most likely cause of lake ecosystem instability.

5) Diatom analysis of cores from the coastal sites as well as the collection and analysis of long cores from sites within the Merja Zerga are required to fully evaluate the impacts of recent environmental change at the coastal wetlands.

6) Compared with expensive long-term monitoring, examination of sedimentary records from valued wetlands offers a convenient way of establishing recent trends in ecosystem change and the likely causes of change. Without such information it is impossible to assess the contemporary ecological status of a site fully.

7) Information about sustained rates of ecological change and the composition of past and present communities is essential if management authorities are to conserve important wetlands effectively.

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Appendix 1   Epiphyton in Lac Azigza - J.R. Carter

Diatom analysis of the epiphytic diatom community on *Ranunculus* from a depth of 3 m in Lac Azigza was carried out by J.R. Carter. The community was very diverse and complex. Some taxa are unusual and poorly described; the taxa encountered are as follows:

Achnanthes minutissima.

Amphora sp. (close to montana Krasske).

Calonies amphisbaena, C. permagna (small forms).

Cyclotella ocellata (but occeli rather smaller than normal).

Cymbella microcephala (present in a variety of forms).

Epithemia sorex, E. adnata.

Fragillaria capucina (sensu L.-Bertalot 1985), *F. pinnata, F. abreviata*.

Frustulia vulgaris.

Gomphonema parvulum

Navicula anglica, N. capitata v. *hungarica, N. cryptocephala, N. cryptonella* (but with slightly finer striae - 21 in 10 μm), *N. bacilloides, N. erifuga* (cf. *N. cinctaeformis*), *N. gastrum* (all small), *N. tenelloides, N. trivialis, N. veneta*.

Neidium binodiformis, N. dubium, N. affine.

Nitzschia frustulum, N. rosenstockii, N. recta, N. delongnii, N. angustata, N. capitellata, N.

pusilla, N. cf. *incognita* (striae 40 in 10 μm).

Rhopalodia gibba, R. operculata (tentatively).

Surirella gracilis (moelleriana sensu Hust.), *S. bifrons*.

Synedra cf. *tenera*.