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Smir Lagoon (Northern Morocco) and its surroundings: an environmental management approach

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Abstract. The environs of Smir Lagoon comprise a patchwork of coastal habitats including sand dunes, saline marshlands and watercourses. Recent development in the vicinity has generated a shift in the dynamics of physical systems and biological communities of the area. Much of the environmental impact derives from the construction of a dam at Oued Smir, the construction of residential and tourist accommodation on the beach and dunal area and from the discharge of wastewater into the sea. Sand dune systems on the Smir sea-front were subject to attrition and loss of foredune mass as a consequence of interception of sediment by small-scale timber constructions on the beach. This change in dunal dynamics is being reflected in structural and compositional shifts in plant communities. The plant communities in the area were all characterized by the superimposition of a suite of opportunistic species on the original climax vegetation as a consequence of the availability of habitat-space vacated through direct or indirect disturbance. Analysis of dipteran fauna indicated a high proportion of generalist species suggesting the gradual replacement of specialist forms by a broad-spectrum assemblage. Avifaunal diversity was high, consistent with the function of the lagoon as a staging post along an important migration route.

Keywords: Smir lagoon, coastal dunes, plant communities, diptera bio-markers, environmental management.

La lagune de Smir (Nord du Maroc) et ses environs: une approche de la gestion de l'environnement.

Résumé. Les environs de la lagune de Smir comprenant les dunes du sable, les terrains marécageux salins et les cours d'eau constituent un réseau d'habitats côtiers. Le développement récent de la région a provoqué un changement dans la dynamique physique des systèmes et des communautés biologiques de ces habitats. Les nombreux impacts sur l'environnement identifiés sont dus à la construction d'un barrage sur l'Oued Smir, de résidences et de complexes touristiques sur la plage et la zone dunaire et aux rejets d'eaux usées. Les systèmes de dunes de sable sur le front de mer sont soumis à l'érosion et à la perte de masse de l'avant-dune à la suite de l'interception du sédiment par les constructions sur la plage. Ce changement dans la dynamique dunaire est reflété dans les changements de la composition et de la structure des peuplements végétaux. Ces derniers sont tous caractérisés par la superposition d'une suite d'espèces opportunistes sur la végétation climacique originale comme conséquence de la réduction de la disponibilité de l'espace de l'habitat suite aux différentes contraintes subies qu'elles soient directs ou indirects. L'analyse de la faune de diptères indique une forte proportion d'espèces dites généralistes ce qui suggère le remplacement graduel des formes spécialisées par un assemblage à spectre général. La diversité de l'avifaune est élevée, ce qui concorde avec l'importance que revêt la lagune en tant que voie et relais pour les oiseaux migrateurs.

Mots clés: lagune de Smir, dunes côtières, peuplements végétaux, diptères bio-marqueurs, gestion de l'environnement.

INTRODUCTION

In the last ten years the town of M'diq, on the eastern coast of the Tétouan promontory, northern Morocco, experienced a tourism-related development that brought about demographic growth coupled with a surge of urban expansion, particularly along the littoral, and has led to significant changes in land-cover and conflicts of land-use.

General description of the area of study

The study area at M'diq comprises Smir Lagoon, Smir beach (the beach located between M'diq and the area adjacent to Smir Lagoon) and the hinterland leading to a recently constructed dam and, as a result, an artificial lake, located at the headwaters of oued Smir. Smir Lagoon lies a short distance from a sandy shoreline known as Smir beach, which forms part of an extensive linear beach that lies on the embayment that stretches between Sebta and Cabo Negro. Prior to construction of the dam, the lagoon's hydrology was dependent on the uplands located westward of it. Thus, the lagoon and a significant sector of Smir beach and adjacent dunal area depended largely on fluvial fluxes that formed part of a complex hydrological system that originates on the Jbel Zemzem slopes. At the time, freshwater channelled from the Jbel Zemzem catchment towards the coast, first via Oued Lil and Oued Jerjon, then onward into the Oued Smir conduit. The headwaters of the former valleys originate on either extremity of the Zemzem foothills. From Oued Smir, water would then nourish the wetland areas inland of the lagoon and, subsequently,

replenish the lagoon. Presently, the sediment-rich freshwater, which once flowed downstream towards Smir beach carrying large quantities of terrigenous material, important for beach and dune nourishment, is now being entrapped within the artificial lake as a result of the dam. Moreover, following engineering works at beach level that created a link with the open sea at a point beneath the elevated thoroughfare that connects M'diq with Fnideq, the lagoon is now regularly inundated with seawater, especially at high-tide. Both the lagoon's bathymetry and its chemistry have been significantly modified (Bayed & El Agbani 2002).

Objectives of the study

The objectives of the studies undertaken may be summarized into the following broad categories:

a) Collection of baseline vegetation data in order to characterize the biotopes present in the area of study.
b) Characterization of the diptera indicators in the area of study.
c) Assessment of the locality's importance in terms of its potential for eco-tourism.
d) Identification of the environmental impact of anthropogenic activity in the area and its immediate surroundings.
e) Recommendation of possible strategies for mitigation of environmental impact through contextual use of biological and geomorphological data.

MATERIALS AND METHODS

Sampling programme

Fieldwork was carried out over a period of three years, between 1999 and 2001, during which four field visits were conducted. These were undertaken during the months of April (2001), May (2000), July (1999) and October (2000).

Phytosociological description

Habitats were examined during walkover surveys and characterized by visual assessment of geomorphological features and biotic assemblages. Biotic communities were identified on the basis of conspicuous vegetation and subsequent mapping of these units was based on ground surveys. Dominant and indicator species were noted, while accompanying species were also recorded. No attempt at compiling an exhaustive inventory of the biota was made since such an exercise would require extensive sampling at seasonal and diurnal intervals. Population density of macrophytes was estimated using quadrats and used to identify any trends in the distribution of vegetation. The raw data collected during the field surveys is available from the authors upon request. Classification of vegetation followed that suggested by Devillers & Devillers-Terschuren (1996).

The floristic data collected were subject to exploratory multivariate analysis using SYSTAT Version 6.0. Hierarchical Cluster Analysis and Principal Components Analysis were carried out on both quadrats and species in order to elucidate any basic patterns in distribution and dominance of species. The results of such analysis would subsequently be used for hypothesis-generation in future studies.

Sampling for Diptera

Three sites: (i) Smir lagoon and the adjacent salt-marsh; (ii) Smir beach and dunes; and, (iii) the Barrage at Smir, were visited during the final research mission to the area. Fieldwork focused on collecting as many species of flies as possible in the limited time available, by standard entomological methods. Collecting involved covering as much ground as possible with a sweep net in suitable biotopes (intertidal zone, beach, exposed ground, bare sand, and vegetation) as well as stalking individual flies when practicable. In addition, some collecting was carried out on a wet meadow in the vicinity of the lagoon. The objective was to identify as much of the collected material as current knowledge and available resources permitted, and to prepare a species list with special reference to shore dwelling and stenotopic species. Specimens collected during the study were supplemented by material collected from pitfall traps in the same locality by Dr Lorenzo Chelazzi in October 2000.

Avifauna

The avifauna of the area of study was assessed qualitatively through direct observation and field identification.

RESULTS

Dune vegetation at Smir Beach

The plant community recorded from the dunal area at Smir beach was generally characteristic of climax sand-dune systems along the Mediterranean littoral. The frequency of invasive generalists colonising the dune habitat suggested ongoing allogenic modification of community dynamics. The binding element within the foredune community was *Elytrigia juncea*, which formed sparse tufts on back-beach deposits (where the angle of slope varied between 12 and 15 degrees) and the foredune area; *Ammophila littoralis* was also locally abundant.

The consolidated dune area was colonised by an assemblage characterized by higher frequencies of K-selected species including *Ephedra fragilis*, *Chamaerops humilis*, *Juniperus phoenicea*, *Pistacia lentiscus* and *Tamarix africana.* Various annual species, including *Reichardia gaditana* and *Delphinium nanum* were also noted from this area. The adjacent roadside is lined with planted *Acacia* spp. trees, forming an extensive and continuous band that runs parallel to the shoreline.

Analysis of the quadrat data (Fig. 1) indicates three clusters of sample points reflecting three main biotopes in the area. The first cluster, comprising Quadrats 1, 2 and 3 represents the wooded *Juniperus*/*Ephedra* community on the consolidated dunes whilst Quadrats 5, 6 and 8 are dominated by species characteristic of sand dune systems (*Pancratium maritimum*, *Ammophila littoralis*, *Helichrysum stoechas*, *Elytrigia juncea*). The third cluster, comprising Quadrats 7 and 4 comprises species characteristic of sand dunes coexistent with species generally typical of saline marshes (*Salsola kali*, *Polygonum maritimum*). Analysis of the species data for

Smir Beach (Fig. 2, Tab. I) confirms the three biotopes indicated by the quadrat data and also highlights the presence of *Carpobrotus edulis*, an invasive alien species.

2. Vegetation within and around Smir lagoon

The vegetation that colonised the area between the main thoroughfare and the lagoon consisted of a mixed assemblage comprising species generally associated with Mediterranean marshland habitats, species associated with fixed dunes and ruderal species (Fig. 5).

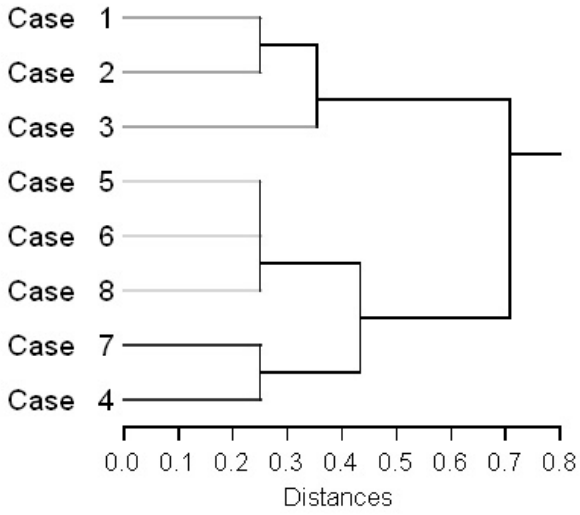

Figure 1. Dendrogram showing relationship between quadrats at Smir beach. Distance metric is Euclidean Distance. The "Case number" in the diagram corresponds to Quadrat number quoted in the results.

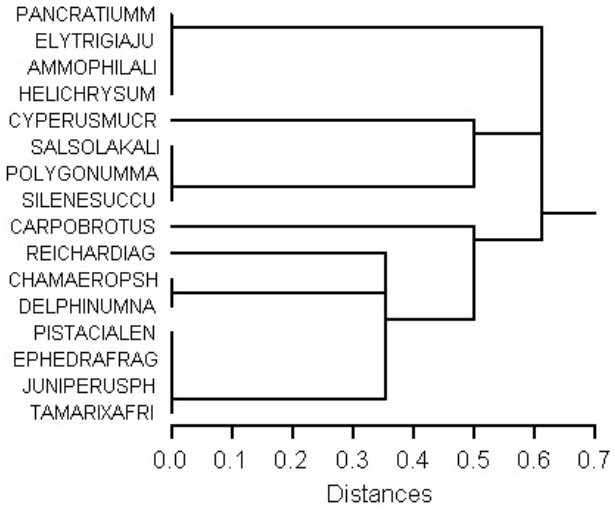

Figure 2. Dendrogram showing relationship between macrophyte species at Smir beach. Distance metric is Euclidean Distance. Taxonomic names corresponding to the condensed species labels in the diagram are given in Table I.

The vegetation recorded from the north-northwest sector of the lagoon comprised marshland vegetation such as *Arthrocnemum macrostachyum* and *Juncus* spp. along the fringes of the lagoon and a steppe community further inland. Other species recorded (in low population densities) from this part of the site included *Limonium ferulaceum*, *Limbardia (=Inula) crithmoides, Spergularia* sp., *Paronychia argentea, Plantago coronopus* s.l., *Avena barbata* s.l., *Cressa cretica*, *Frankenia pulverulenta* and *Paspalum vaginatum.* Closer to the lagoon proper, slightly deeper regions characterized by longer hydroperiods and higher soil moisture content were dominated by *Arthrocnemum macrostachyum*, often accompanied by *A. fruticosum*. Regions away from the edge of the lagoon, where hydroperiods were shorter and soil moisture content lower; the dominant species was *Juncus acutus*. The marsh area was colonised by relatively large populations of *Paspalum vaginatum*, an alien species, and *Centaurium tenuiflorum*.

Further inland, a minor watercourse formed a water channel approximately 60 metres in length from the lagoon. The plant community in this part of the habitat consisted of a water-fringe cane-bed assemblage, characterized by a thick belt of *Typha domingensis*, along the sides of which was noted a broad cover of *Juncus rigidus* (becoming more extensive closer to the lagoon), together with *Dittrichia viscosa* and *Gomphocarpus fruticosus*. Higher ground (with consequently lower levels of soil moisture) comprised extensive cover of *Dittrichia viscosa* associated with *Tamarix* sp. and *Limonium ferulaceum*.

The north sector of the lagoon was characterized by low-lying land with numerous shallow depressions typical of Mediterranean salt meadows (Juncetalia maritimi). Dominant cover was contributed by *Arthrocnemum macrostachyum* and *Juncus rigidus*. Other species, including *Salicornia europaea* s.l. and *Suaeda maritima* were recorded in lower abundance.

It should be noted that a band of Tamarisk trees near the lagoon proper was subject to progressive decrease in number throughout the duration of the study. Evidence of physiological stress was already visible during the first survey (1999) and subsequent observations confirmed the loss of individuals and increasing physiological stress in remaining ones. No attempt at correlating these results with changes in environmental factors was made.

Table I. Taxonomic names corresponding to condensed species labels in figure 2.

Label	Species
PANCRATIUMM	*Pancratium maritimum*
ELYTRIGIAJU	*Elytrigia juncea*
AMMOPHILAL	*Ammophila littoralis*
HELICHRYSUM	*Helichrsyum stoechas*
CYPERUSMUCR	*Cyperus mucronatus*
SALSOLAKALI	*Salsola kali*
POLYGONUMMA	*Polygonum maritimum*
SILENESUCCU	*Silene succulenta*
CARPOBROTUS	*Carpobrotus edulis*
REICHARDIAG	*Reichardia gaditana*
CHAMAEROPSH	*Chamaerops humilis*
DELPHINUMNA	*Delphinium nanum*
PISTACIALEN	*Pistacia lentiscus*
EPHEDRAFRAG	*Ephedra fragilis*
JUNIPERUSPH	*Juniperus phoenicia*
TAMARIXAFRI	*Tamarix africana*

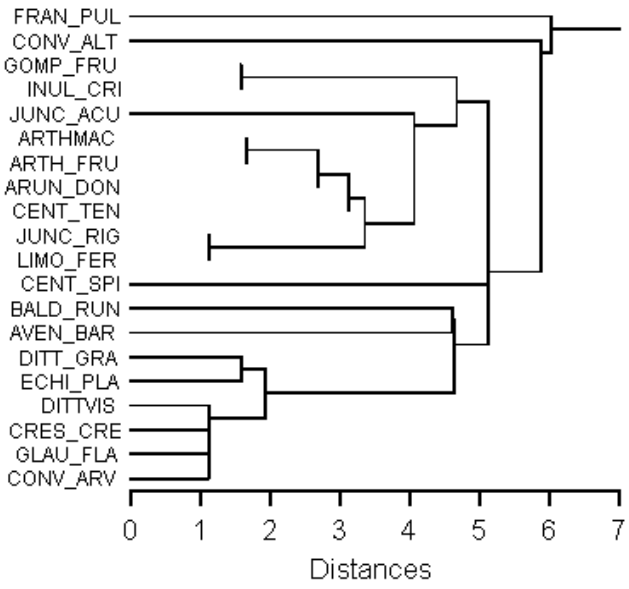

Figure 3. Dendrogram showing relationship between macrophyte species at Smir. Distance metric is Euclidean Distance. Taxonomic names corresponding to the condensed species labels in the diagram are given in Table II.

Table II. Taxonomic names corresponding to condensed species labels in figure 3.

Label	Species
FRAN_PUL	*Frankenia pulverulenta*
CONV_ALT	*Colvolvulus altheoides*
GOMP_FRU	*Gomphocarpus fruticosus*
INUL_CRI	*Limbardia* (=*Inula*) *crithmoides*
JUNC_ACU	*Juncus acutus*
ATRHMAC	*Arthrocnemum macrostachyum*
ARTH_FRU	*Arthrocnemum fruticosum*
ARUN_DON	*Arundo donax*
CENT_TEN	*Centarium tenuiflorum*
JUNC_RIG	*Juncus rigidus*
LIMO_FER	*Limonium ferulaceum*
CENT_SPI	*Centaurium spicatum*
BALD_RUN	*Baldellia ranunculoides*
AVEN_BAR	*Avena barbata* s.l.
DITT_GRA	*Dittrichia graveolens*
ECHI_PLA	*Echium plantagineum*
DITTVIS	*Dittrichia viscosa*
CRES_CRE	*Cressa cretica*
GLAU_FLA	*Glaucum flavum*
CONV_ARV	*Convolvulus arevnsis*

Further north, at the foot of a hillock immediately adjacent to the lagoon (until recently a cultivated area), vegetation cover consisted of species generally considered indicative of disturbed environments interspersed with species of dry calcareous steppe. Species recorded from this part of the habitat included *Avena barbata* s.l., *Aster* sp., *Dittrichia viscosa*, *Convolvulus arvensis*, *Verbena* sp., *Polygonum ?aviculare*, *Lythrum hyssopifolia* and *Dittrichia graveolens.* A bramble thicket (*Rubus ulmifolius*), approximately six meters across, was noted at the foot of the hillock. This thicket may represent a remnant of a previously more extensive Quercetea-ilicis assemblage. Further remnants of this presumed assemblage, including *Pistacia lentiscus* and *Quercus coccifera*, were noted along the track that surrounds the lagoon. Other species present in this area included *Convolvulus althaeoides* and *Tamarix* sp. The disturbed area supported a vegetation cover generally considered typical of such environments, including *Ricinus communis*, *Dittrichia viscosa* and *Silybum marianum* together with planted/naturalised individuals of *Acacia karroo.* Much of the run-off water that flowed downstream from the uplands towards the coastal plain at Smir is channelled through culverts in the soil surface, the excavated material of which is used to create embankments. Both culverts and aligning embankments serve to control water flow for agricultural purposes. At the back of the lagoon, *Senecio bicolor* colonised embankments, while *Phragmites australis* colonised waterlogged areas beneath the elevated dirt track.

The west sector of the lagoon, the area adjacent to the canal, was colonised by a Phragmitetea community, represented by *Phragmites australis* in the canal proper and *Arundo donax* on the elevated embankment. The flat plain was characterized by *Salicornia europaea* s.l. while *Arthocnemum macrostachyum* was noted mainly on the canal fringe, together with *Juncus rigidus, Baldellia ranunculoides* and *Ranunculus peltatus.*

Analysis of the species data (Fig. 3, Tab II) suggests several small groups of species characterized by restricted distribution in the area of study with no species occurring throughout. The PCA plot indicates a small number of species characterized by extremely specific habitat distributions.

Analysis of the quadrat data (Fig. 4) indicates two sites (Quadrat 19 and Quadrat 2) characterized by high plant diversity (14 and 15 species respectively). All other quadrat points comprised not more than 4 species. Three quadrat points comprised a single species.

The data and analysis indicate a habitat characterized by relatively high heterogeneity. The root cause of this habitat-heterogeneity may be associated with physico-chemical factors, colonisation dynamics, interspecific competitive interactions, or a combination of all of these. Subsequent studies would focus on the collection of abiotic data at each quadrat point in order to permit the correlation of biological data with physico-chemical parameters.

Diptera

A total of 193 species from 46 families were collected. More than half of these (111 species) have been identified to species level, 60 to genus, 13 tentatively to species or genus, and 9 remain unidentified. More material, literature, and museum work will be necessary in order to complete identification of all the collected material.

A surprising 24% of the taxa identified, including some very common and widespread species, have been found to be new to the fauna of Morocco while 5% of species recorded in this study are also new to the fauna of North Africa. It is expected that further study will reveal undescribed species amongst the 14 species of Hybotidae

that have been collected. Most of the Diptera encountered were species of wide geographical distribution that are common in similar habitats along the Mediterranean littoral and elsewhere.

Some records are however notable. For example, *Psilopa rutilans* was collected from the lagoon and salt-marsh at Smir. This species was described from Italian material collected from coastal biotopes and thermal springs (Canzoneri & Meneghini 1972). This is the first record of the species outside Italy. *Psilopa maritima* is known from the coast of Spain but not yet from North Africa (Mathis & Zatwarnicki, 1995). *Tethina yaromi* was described from Almeria in Southern Spain (Mathis & Munari 1996); this is the first record of this species outside Spain.

Fewer than half the species (45%) were collected from the lagoon and salt-marsh, the fauna of which were essentially similar. Thirty one of the species were taken exclusively from the beach and dunes. Eighteen species were common to both lagoon/salt-marsh and beach/dunes.

A small number of species (c. eight) were taken from a small meadow close to the lagoon. These included typical meadow/woodland species in the genera *Empis*, *Helina* and *Hydrotaea*, as well as *Sphenella marginata*. Ten species of flies were collected from the maquis surrounding the Barrage at Smir. These could broadly be divided into carrion feeders (including species developing in earthworms): *Bellardia* sp. *Pollenia* sp., *Sarcophaga lehmanni*; parasites: *Stomorhina lunata* (larvae in egg pods of locusts); predators (which use shrubs as vantage points): *Machimus* sp., *Saropogon* sp.; and, typical woodland genera such as *Medetera* (larvae in the galleries of bark beetles), *Rhamphomyia*, *Bicellaria*, and *Oropezella sphenoptera.*

Grazing by cattle was common in the lagoon and salt-marsh areas, and some families of flies which depend on cattle, or their droppings, for survival, were fairly well represented. These included the Sepsidae, Sphaeroceridae, Tabanidae and Oestridae. Some large and important families (Bombyliidae, Chironomidae, Empididae, and Tachinidae were however grossly under-represented. Some of these (e.g. Empididae) are early spring species and may well have been missed. Others, such as the Bombyliidae and Tachinidae, are parasites essentially of Hymenoptera and Lepidoptera respectively, and depend heavily on an abundant and diverse flora for their success. It may be that lack of rainfall in the wet season (2000/01) culminated in a flora, which did not meet these specific requirements.

Of the stenotopic dipterans listed by Ardö (1957), *Eutropha fulvifrons*, *Fucellia maritima*, *Hecamede albicans*, *Helcomyza ustulata* and *Scatella subguttata* have been recorded in the present study. A further 23 species of Diptera in 7 families collected at Smir are regarded as tychocoenic *sensu* Backlund (1945) i.e., they may be found both on sand dunes and other related communities (e.g. wrack beds). Whilst fully adapted to the dune biotope, their ecological range is wider than that of the stenotopic species. Examples include species in the genera *Aphaniosoma*, (Chyromyidae), *Sciapus* (Dolichopodidae), *Atissa*, *Glenanthe* and *Psilopa* (Ephydridae), *Chersodromia* (Hybotidae), *Rachispoda* and *Thoracochaeta* (Sphaeroceridae), *Tethina* (Tethinidae) and *Trixoscelis* (Trixoscelididae).

These observations suggest that the dipterous fauna of the area is similar to that of southern Spain, and the data obtained may be useful in augmenting what is already known of the Diptera of that region. Apart from its value in highlighting the presence of indicator species in the study area, the data is also useful as a baseline for the assessment and conservation of dipteran biodiversity in the region.

Avifauna

The avifauna recorded during the period study is listed in table 3. The Smir dam area, which includes the large stretch of open water formed by the artificial lake behind the dam proper, should attract open-water birds such as ducks and grebes. The surrounding shore, on the other hand, did not appear to offer much suitable habitat for waders as it is too steep and rocky and, as yet, not too vegetated. Great Crested Grebe (*Podiceps cristatus*) was among the birds noted in significant number over the artificial lake. The nearby uplands, dominated by Jbel Zemzem, a mountain somewhat isolated from the Dorsale Calcaire, are located quite close to the artificial lake and relatively close to the coast. The topography of this area appears decidedly suitable for soaring raptors, both to utilize it for slope-lift and for the provision of thermals under suitable meteorological conditions, as also to use the wooded areas on its slopes for roosting purposes. In this respect, however, more detailed observations would be required with regard to Jbel Zemzem.

From a conservation viewpoint, the *Platalea* population is exceedingly important and every effort should be made to afford adequate protection to both species and habitat. Of particular importance is its roosting site and the lagoon, where these birds tend to forage.

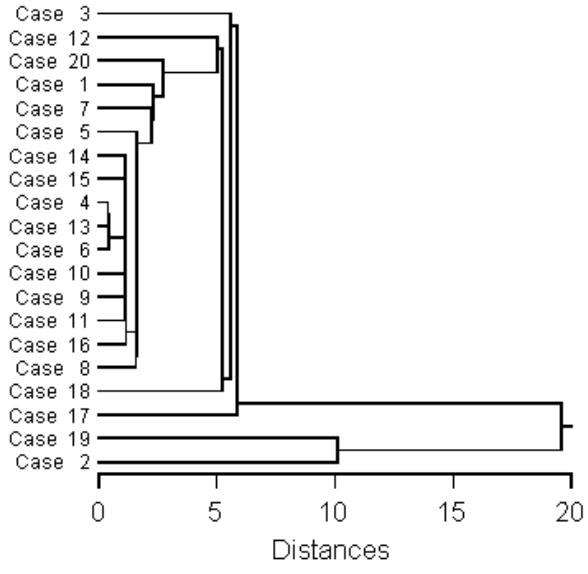

Figure 4. Dendrogram showing relationship between quadrats at Smir. Distance metric is Euclidean Distance. The "Case number" in the diagram above corresponds to Quadrat number quoted in the results.

Table III. List of avifauna species recorded during the period of study (1999-2001)

Great Crested Grebe (*Podiceps cristatus*)	Significant number over the artificial lake
Squacco Heron (*Ardeola ralloides*)	Relatively common in emergent vegetation
Cattle Egret (*Bubulcus ibis*)	Very common
Little Egret (*Egretta garzetta*)	Occasional
Grey Heron (*Ardea cinerea*)	Within the lagoon
Purple Heron (*Ardea purpurea*)	Breeds in *Phragmites* stands
White Stork (*Ciconia ciconia*)	Breeds in close proximity of lagoon
Spoonbill (*Platalea leucorodia*)	Breeds on vegetation thickets on the consolidated dune at Smir beach. A small population numbering some eleven pairs was observed during each research mission
Greater Flamingo (*Phoenicopterus ruber*)	Occasional within the lagoon
Marsh Harrier (*Circus aeruginosus*)	Fairly common in *Thypha* and *Phragmites* stands
Moorhen (*Gallinula chloropus*)	Within lagoon
Coot (*Fulica atra*)	Within lagoon and artificial lake
Black-winged Stilt (*Himantopus himantopus*)	Occasional small flocks within lagoon
Stone-curlew (*Burhinus oedicnemus*)	On steppic areas near lagoon
Little Ringed Plover (*Charadrius dubius*)	On lagoon mudflats
Curlew Sandpiper (*Calidris ferruginea*)	On lagoon mudflats
Little Stint (*Calidris minuta*)	On lagoon mudflats
Yellow-legged gull (*Larus cachinnans*)	On Smir beach and Smir lagoon
Bee-eater (*Merops apiaster*)	Relatively common
Zitting Cisticola (*Cisticola juncidis*)	Quite common

Sources of environmental impact

Coastal development and associated activity that affected the environment of the lagoon and its surroundings was significant; as a result, the magnitude of the impact is likewise expected to be considerable. Impacts that were observed or inferred included the following.

Area around Smir lagoon

Construction of marina on seaward side and subsequent linking of lagoon with the sea. This brought about a complete change in the physico-chemical characteristics of the lagoon, which is fast becoming a salt-water pool. It is killing off less-resistant vegetation in the lagoon, either through increased salinity or water logging (there is evidence of salinisation in the soil around the lagoon). This has already resulted in the death of a large *Tamarix* stand at the centre of the lagoon.

Construction of main thoroughfare along the back of Smir beach. Road construction has mainly impacted the dune area. However, its presence has brought about a distinct change in the environment of the lagoon as well as increased access. The presence of the road increases pollution from SO_x, NO_x, CO_x and other volatile compounds emitted in car exhaust. Furthermore, the passage of cars in this busy road has elevated noise levels in the area and introduced light disturbance from car headlamps at night, which can have an impact on the fauna, particularly birds, of this important wetland.

Grazing activity by cattle and camels. Grazing activity around the lagoon and marsh area, though not substantial, is appreciable. This results in the cropping of vegetation as well as the introduction of natural fertilisers into the area as a consequence to bio-solid waste.

Trampling. This is a direct effect of the previous activity; while its effects are limited to grazing activity by domestic animals as well as by humans, compaction of the soil, especially in view of a possible increase in waterlogged conditions, should not be underestimated.

The effect of the dam and reservoir built upstream of the lagoon. The effects of the dam and artificial reservoir on the downstream portion of the Oued and the lagoon have led to the most notable impacts in the whole area. While the construction of the dam was an important measure from an economic and social point of view, its environmental impacts have been, and still are, considerable. The major impacts can be summarised as *(i)* a drastic reduction in the water flow through the valley; *(ii)* a radical change in the humidity levels and physical characteristics of the valley with a concomitant change in the floral content of the valley; *(iii)* a significant "starvation" of the lagoon system of freshwater with the result that the lagoon became increasingly brackish; *(iv)* a complete change in the hydrology of the lagoon, dune and beach system; and, *(v)* a notable reduction in the sediment load previously transported via the valley and, therefore, a reduction in beach replenishment[1].

Conversion of the marshland surrounding the lagoon into agricultural land. It is evident that there have been a number of attempts at converting parts of the marshland surrounding the lagoon into agricultural land. The agriculture practiced is dry farming and the crops grown appeared, at the time of respective surveys, to consist of cereals. Between the research team's penultimate and last mission to the area, at least two fields have been so converted. Further encroachment onto this area should be avoided at all costs.

[1] This needs to be carefully researched. It is not clear whether the amount of sediment that finds itself in the reservoir is monitored and whether any measures are taken to control sediment input, although the large size of the reservoir may obviate the need for early intervention.

Cutting down of the Tamarisk stand for use as firewood. Most of the woody shrubs present in the central parts of the lagoon (predominantly *Tamarix*) have died off. Regeneration of these tree species further away from the lagoon's shores is however evident. Nonetheless, there is also evidence that the dead stands are being removed and the wood used possibly as firewood; a possible destination being the kilns present in the hinterland region of the lagoon. While the re-use of dead wood in this manner is acceptable, a percentage of the material should be allowed to decay *in situ* to return at least part of the organic matter back into the ecosystem.

Dumping of construction and demolition waste on the marshland adjoining lagoon. Several areas, especially to the west of the lagoon (near the village of M'diq) have suffered from considerable dumping of construction and demolition waste. The reason being is to form tracks across the marshland and leading, in some cases, to constructions within the marsh. These roads, apart from obliterating habitat and introducing alien materials, are also interfering with the flow of water towards the lagoon. The removal of all this dumped material and the area's rehabilitation should be sought as a matter of priority.

Fly-tipping onto the lagoon and marshland. Another chronic impact relates to the tipping of waste into the lagoon precincts, especially in areas within easy reach of the road circling the lagoon. Considerably more tipping is present along the roads skirting the hinterland side of the lagoon than is present on the seaward side of the same feature.

Construction activity on the marshland and adjacent land, including the expansion of M'diq with consequent land take-up. Some constructions are also present in the marsh itself between the village of M'diq and the lagoon proper. Apart from this, the expansion of the village of M'diq towards the marsh/lagoon system is poised to threaten this same habitat, which has the potential to generate considerable interest in eco-tourism to the area. A way of meeting the social and economic needs of the area (as exemplified in the construction of the new part of M'diq), with the environmental concerns of this important ecosystem should be found with urgency. The expansion of infrastructural works for the area should progress in parallel with the expansion of urban development to avoid overloading the existing systems with the risk of increased pollution in the area.

Impacts from sewage overflow into the marshland. The current sewerage system for the village of M'diq seems not to be coping with the recent increase in the size of the village[2]. This is resulting in sewage overflows into the marshland surrounding the lagoon. Furthermore, it is not clear whether the sewage treatment plant located on the lagoon-side of the main road is actually in use. It is therefore important that the necessary upgrades to the sewerage network in the area are undertaken and the overflow of sewage into the marshland be eliminated altogether.

[2] During visits to the area it was noted that major infrastructural upgrading works were in hand within the area.

Barrage and hinterland

The dam and reservoir upstream of l'Oued Smir impacted on the downstream characteristics of Oued Smir and the water catchment draining into Smir Lagoon. Its construction has drastically reduced the flow of fresh water through the Oued and into the lagoon with consequent shifts in vegetation dynamics within the Oued and in hydrological balance of the lagoon. The latter problem was further compounded by the infiltration of seawater from the marina into the lagoon.

Further environmental impact in this area arose from the extensive reforestation that was undertaken in large tracts of the hinterland. The type of afforestation undertaken has not always been contextually appropriate and the tree species used (mainly Maritime Pines - *Pinus pinaster*) have the potential to alter the physico-chemical characteristics of the soil with consequent impact on the characteristic flora of the area. Moreover, any large-scale regeneration of pines would displace indigenous flora. Apart from the loss of biodiversity arising from degradation of maquis and accompanying understorey vegetation, alterations in the hydrological regime on the surrounding slopes of the hinterland may also occur. In addition to providing an appropriate habitat, in this case a maquis community, the presence of trees and other vegetation on slopes retards run-off of surface water, promotes aquifer recharge and reduces rates of soil erosion.

Smir beach and sand dunes

Like other sandy areas in the Mediterranean, Smir beach is subject to insensitive development, which has, over the years, degraded a previously extensive sand dune ecosystem. The original sand dune system was, at the time of survey, bisected by the main thoroughfare that links M'diq with Fnideq and encroached upon by *ad hoc* car-parks, afforestation and constructions, ranging from hotels and tourist complexes to marina developments and private residences. The dune remnants on the lagoon side of the road have also been subject to various pressures, including introduction of inappropriate species (such as *Eucalyptus* sp.), grazing (camels, donkeys and cattle) and trampling (vehicles, humans and animals).

The foredunes and beach were further stressed by the passage of eutrophic water through a canal incised into the sandy substrate, approximately mid-way along the length of the beach. The point of origin of the water and its precise chemical load were not determined.

DISCUSSION AND CONCLUSIONS

Dune morphology

The results compiled over the three-year project cycle suggest a general lack of coherence between the beach and the dunal components. For example, the numerous semi-permanent timber shacks that occur on the rear sector of the beach and foredune area have contributed towards a decline in sand deposition, as these structures act as physical barriers that impede sediment transfer from the beach zone to the dunes. In fact, the dimensions of the foredune and the main dune ridge (consolidated dunal area) are clearly

disparate. Whereas the remnant foredune is mostly less than a metre high, the consolidated dune immediately adjacent to the foredune exceeds a height of five metres. Such a scenario suggests that the consolidated dune was, in the past, nourished by an active, indicatively large foredune, which now appears to have lost a great deal of its mass. A permanent structure, which appears to have caused a negative impact on sediment transfer and depositional processes, includes a perimeter wall that was constructed along the length of the beach. Notwithstanding its relatively low structure, the wall, like other structures on the beach, also acts as a sediment trap, as a result of which, sand movement across the beach surface is hindered. Meanwhile, erosional processes, through the agency of run-off and wind, continued to deplete the beach surface of sand grains. As this dual process continues, that is, a sustained depletion of sand material through erosion coupled by a continual impediment of sand nourishment processes, the foredune is likely to experience a marked loss of material thus leading to long-term deflation of the dunal mass (Cassar & Stevens 2002).

Biological indicators

Anthropogenic modification of the physical conditions of the dunal area has accelerated ecological degradation of the climax sand-dune community. In general, species composition tends to be depauperate relative to comparable dunes in other parts of the Mediterranean littoral. Habitat degradation in parts of the dune area was sufficiently severe to cause localised extirpation of characteristic dune vegetation with, in many cases, subsequent colonisation of the vacant habitat-space by invasive generalists. The assemblage colonising the foredune, in particular, has been subject to considerable and progressive degradation over the course of the present study, a trend that is consistent with the increasing popularity of the area with tourists. The data generally indicate that the present assemblage colonising the area of study is a transient, low-stability phase between equilibrium communities. Although three general biotopes were identifiable, the distinction between them will progressively decrease as infiltration of opportunistic forms raises the proportion of common denominators in all parts of the area. These continuous shifts in community composition are likely to persist for as long as abiotic changes are ongoing. Interpretation of dynamic patterns in the Diptera is less straightforward as no baseline community data was available prior to the study. The species recorded included a high proportion of generalist species suggesting the gradual replacement of specialist forms by a broad-spectrum assemblage in response to decreasing stability of the abiotic conditions.

Assessment of environmental risks and impacts

Various risks and impacts may be identified as a result of human activities within and beyond the immediate Smir Lagoon area. While it is acknowledged that the economic momentum attained, particularly from tourism, is maintained and possibly enhanced, every effort should be directed towards conserving the natural resources of the region. Apart from the immense aesthetic value of the coastal and mountainous areas, the Smir Lagoon and its surroundings are potentially significant as staging point for migratory avifauna. Bearing in mind the importance of this western-most Old World major passage route (= north-western Morocco/Iberian peninsula) (Cramp & Simmons 1982), wetlands located within this geographical region would act as 'migrant trap' as birds converge on the Tetouan promontory during passage, later fanning-out into the Iberian interior (in the case of spring migration).

Existing threats and impacts in the area are varied. Primarily, they stem from the construction of the dam at l'Oued Smir, which has led to a considerable depletion of sediment downstream of this infrastructure. As a consequence, sediment-free water flowing down-stream has led to scouring of the banks of l'Oued Smir. Moreover, a substantial decrease in sediment loads reaching the coast is expected to have a negative influence on beach/dune nourishment processes in the short/medium term. This will eventually lead to a sustained net deficit of beach sand and, subsequently, a loss of foredune mass due to a lack of sediment transport and deposition (Cassar & Stevens 2002). In addition, the planting of alien plants, particularly invasive species such as *Carpobrotus*, on the dunal area for sand-fixing purposes is also having a negative impact on both the foredune and its stenotopic vegetation.

The dam construction has also reduced the amount of water that once flowed seaward; resulting in its inability to replenish the freshwater body in Smir Lagoon, while the recent breach that brought about a direct physical land-sea connection has had a notable effect. Primarily, the influence of tidal fluctuations has led to a dramatic rise in salinity levels within the lagoon that will no doubt bring about changes in the biotic make-up. It is expected that freshwater and halophytic vegetation will, in time, be wholly replaced by halophilic species. On a positive note, water-level fluctuations as a result of tidal cycles have thus increased the 'feeding edge' for wading birds, particularly at low tide.

The construction of hotel complexes and large private villas directly on the beach and dunal zone as well as the discharge of wastewater into the sea are also the cause of significant direct negative impacts on back beach deposits and coastal dunes.

Most of the impact on the barrage and hinterland is related to the construction of the dam. This includes the beneficial impacts related with the development, that is, that of containing water for storage and more prolonged use for human activities. Depending on the actual construction of the reservoir[3], the slowing of the water flow and extended storage may also help in aquifer recharge and to reduce the erosive force of strong water flow.

The canal excavated in the beach sand was not investigated thoroughly. Nonetheless, it was observed to conduct a flow of contaminated water towards the shore. Further study would need to establish the following:

1. Whether the water is channelled from the hinterland all the way to the sea and collects organic material and other nutrient-enriching chemicals (such as fertilisers)

[3] It is not clear whether the base and sides of the reservoir are lined and therefore impermeable or whether they allow water to pass through and therefore replenish aquifers.

from the fields and/or the flower beds and lawns of a nearby tourist complex;

2. Whether the water is contaminated by sewage overflows from the nearby developments (including the tourist complex).
3. Whether a combination of the two scenarios listed above is operative.

The precise chemical condition of the water in question can only be determined through chemical analysis. It is probable that the eutrophic stream has a considerable negative impact on the area, both in terms of possible health hazards or environmental overload as well as from an amenity point of view. A detailed survey of the area is thus recommended so that the source of this water and its chemical load is identified and the problem resolved. The channel excavated in the sand may subsequently be restored. If the stream is of natural origin and normally conveys water overflow from valleys and gullies in the hinterland, the nutrient source causing eutrophication should be identified and the problem rectified.

Recommended actions for mitigation of environmental impact

Among the recommendations being put forward as a partial solution to the problems encountered at the lagoon is the occasional release of water from the reservoir[4] in order to replenish the lagoon. While this is important to redress the imbalances in the physico-chemical properties of the lagoon, serious consideration should be given to the impact that this may have on the valley. This is because the increase in water flow in the valley may increase soil erosion downstream now that the water flow has been so drastically reduced. This may in turn increase sediment loads in the lagoon and marina. An assessment of the sediment accumulation in the reservoir together with a monitoring programme on the erosion of the valley banks should be carried out if such a plan of action is decided upon.

Another recommendation that needs to be actively considered is the repair of the concrete barrier between the thoroughfares that separates the lagoon from the marina. This was originally intended for seawater to flow into the lagoon only at high tide. However, part of this barrier is currently damaged with the result that there is a quasi-continuous connection to the sea. The restoration of this barrier would minimise the inflow of seawater into the lagoon and restrict it to high tide periods only. This, coupled with the previous recommendation to periodically allow increased flow of freshwater from the reservoir (artificial lake) should help to partially alleviate the current trend towards brackish conditions. Such action, however, needs to be assessed in the light of possible impacts on the marina's operations. Although from a cursory survey of the marina there does not seem to be any particular problem with siltation in the marina basin (except in the area beneath the beacon at the entrance where considerable sediment build-up is evident) one should not discount the possibility that this does occur. Nonetheless, the increased costs of dredging in such an eventuality would need to be weighed against the environmental benefits accrued from improvements in the physico-chemical conditions of the lagoon.

Potential for eco-tourism

Geographically, the region is exceedingly important for its avifaunal bi-annual migration across the Tetouan promontory to the Iberian Peninsula and vice versa. Seen holistically, the study area and its environs provide different biotopes, which have the potential of attracting and supporting numerous species of birds of various groups. In particular, if the lagoon area were to be adequately managed and, if deemed necessary, sensitively rehabilitated, it may provide an additional source of income to the local populace of M'diq, through eco-tourism or more specifically, bird watching. The Tetouan-Iberian Peninsula route is one of the major bi-annual migration paths of Old World passages and, like its eastern counterpart, the Bosphorus, offers good opportunities for observation and research. One advantage is that tourism infrastructure is already established, with several reasonably good hotels that provide accommodation nearby and roads that render the lagoon and its surrounding hinterland quite accessible; this would also diversify the tourist-product on offer, and, as a result, may extend the tourist season into the shoulder and winter months to coincide with birding schedules such as spring and autumn passages, and wintering species.

The Smir lagoon and surrounding wetland site appears to have much potential where avifauna is concerned, particularly in view of its geographical location in relation to migratory birds. The lagoon proper is envisaged to provide a suitable staging point during migration for water-birds such as waders, ducks and heron species. Moreover, the extensive beds of emergent vegetation around its periphery are be expected to be particularly attractive to birds of such habitats e.g. crakes, rails, *Acrocephalus* warblers, Little Bittern, etc. In addition, its coastal location, at the edge of the land-sea interface of the Mediterranean, is expected to be of importance to migrants at both seasons: In spring, it offers a last stopover on the African continent, where migrants may put on further fat before traversing the sea. Conversely, in autumn, it allows birds that have depleted their energy reserves during their southward flight and subsequent sea crossing, a possibility of resting and refuelling immediately on landfall. Furthermore, in winter, the lagoon also serves as a wintering site for discrete numbers of water birds, chiefly ducks and coots.

Subsequent studies should focus on the bathymetry of the lagoon and how this is influenced by tidal action. This should shed light on the diversity of microhabitats available to water-birds, i.e., the extent of suitable substrates at different depths accessible to the different foraging strategies adopted by water-birds. For example, *Calidrine* sandpipers prefer the water's edge; Curlews, Black-winged Stilts, herons and egrets would favour deeper water, while duck species tend to utilize areas of varying depths, from shallow water to yet much deeper water. Such data would be invaluable for planning purposes and would need to be

[4] Although this could be a possibility, the exact construction of the dam and especially whether it contains sluice gates and whether sediment build-up is being monitored and kept in check, needs to be investigated.

taken into account during the preparation of any management plan.

Seen holistically, the entire region with its habitats and biota, comprising the lagoon, beach and dune system, artificial lake and surrounding hills, oueds and vegetated mountain slopes, together with the tourism-related infrastructure presents an ideal setting for rural and eco-tourism, particularly bird watching. As in the case of the Bosphorus, Elat and Monte Ciccia (Messina), Smir could well be developed into a first-rate birding hub in the western Mediterranean.

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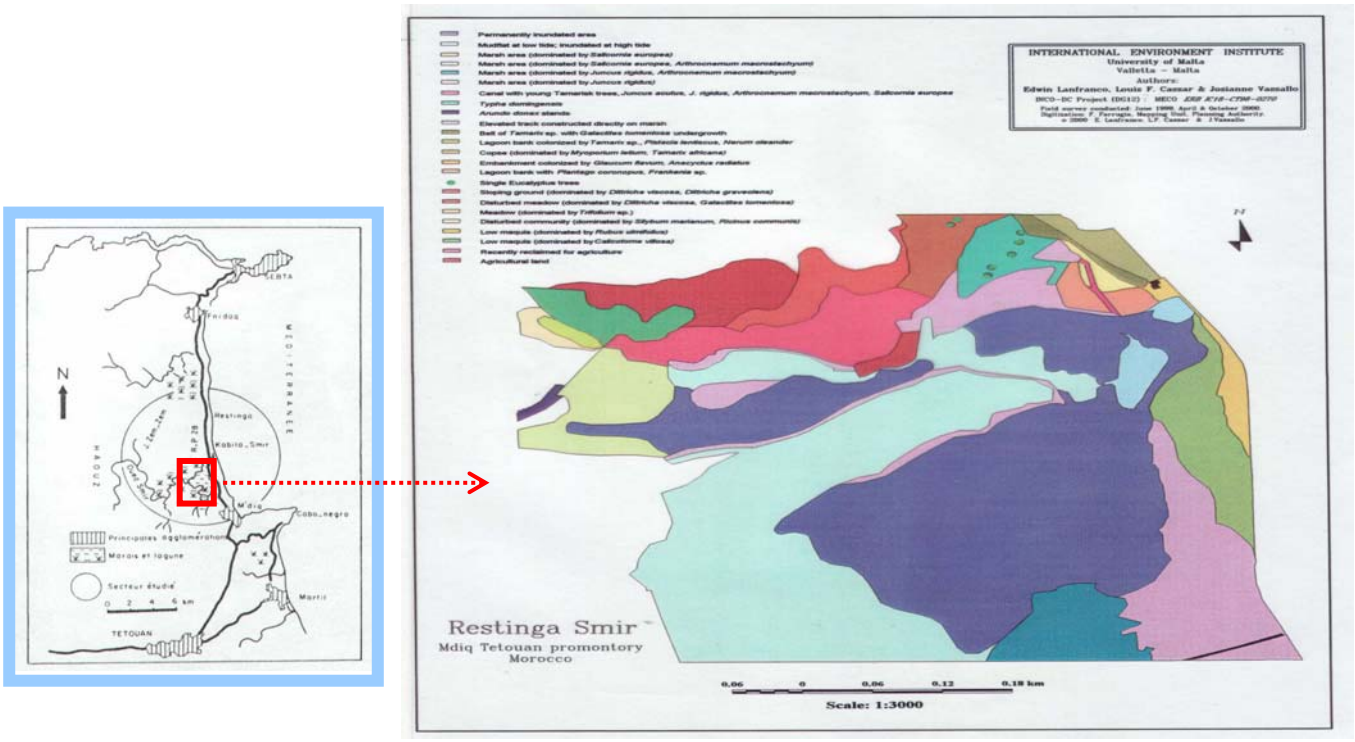

Figure 5. Vegetation distribution map within and around Smir lagoon.