BASELINE RESEARCH FOR THE INTEGRATED SUSTAINABLE MANAGEMENT OF MEDITERRANEAN SENSITIVE COASTAL ECOSYSTEMS

A manual for coastal managers, scientists and all those studying coastal processes and management in the Mediterranean

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INTRODUCTION

Felicita Scapini

The key words in this manual are *diversity* and *integration*. The subjects of study are diverse: the Mediterranean coasts, low or high, with different exposure, small or wide tidal ranges, beaches stretching for kilometres or small pocket beaches, degraded or pristine… Sandy beaches are sometimes peaceful resorts, ideal for sun bathing and relaxing, at other times they are terrifying places because of the force of winds and waves. The seasonal differences in the Mediterranean region are often dramatic, from summer droughts to heavy winter rainfall and floods (Braudel, 1985). Also diverse are the uses of beaches, with fishing villages, coastal cities, ports, natural reserves, mass tourism resorts or élite tourism enclaves. We would like to add marine research stations to this list, but there are not many in the Mediterranean, particularly on the southern coasts.

Modern tourists are largely peaceful but tourism itself creates much damage to the environment. This is in contrast to travellers and explorers in the past who may have carried guns for their own defence but did little damage (Leed, 1995). Activities linked to tourism can be as harmful to the environment as conflicts and wars used to be. Tourism often reduces diversity, construction along coasts destroys natural and cultural heritage. When we speak of the Mediterranean, we must specify which coast, northern, southern, eastern, western, European, non European, Arabic speaking, French, Italian, Spanish, Greek…, and be aware of the cultural and natural diversity.

The Mediterranean is the only internal sea bordered by different continents, Europe, Africa and Asia. These three continents are thus separated or linked, depending on the point of view, by the same sea. The threefold origin of lands explains the diversity of fauna and flora, as well of civilisations. There is one particular plant common on each side of the Mediterranean, the olive tree. Interestingly, this plant is one of the most ancient symbols of peace. The ancient wisdom used to say that the Mediterranean consists of the places where olive trees grow (Matvejević, 1987). Nowadays a common feature of the influence of the Mediterranean sea is the diffusion of plastic debris on the coasts, either abandoned by beach users or deposited by the sea during storms (Löfgren, 2001). Such plastic debris appears as a unifying culture. But such culture is a poor one, less diversified than the ancient ones, which used to exchange valuable products such as silk, olive oil and spices.

Looking back to the past history of the region, it appears that major threats to peace in the region have been the attempts of unification, either starting from the northern coast or from the south, for example the ancient Roman and Punic conflicts. The concept of *integration* should take the place of *unification.* In the past the Mediterranean experienced the Greek-Roman cultural integration and the Arabic one. The current Mediterranean heritage takes much from both. Systems theory explains how integration is achieved. In a complex system diverse elements interact and integrate without losing their characteristics to the advantage of the system. A well integrated system is buffered against disturbing factors. But a system becomes weak as elements get fewer and interactions are disrupted.

The purpose of this manual is to make environmental managers and policy makers aware of the existing diversity in Mediterranean sandy and low coasts, environments highly threatened by economic development, and of the value of coastal diversity in view of sustainable development. This manual proposes concrete tools and practical methods. It shows that the conservation of natural heritage is not only important theoretically but also feasible in reality. The manual presents the experience of the three year "MECO project". This project (1998-2001) was financially supported by the European Commission in the framework of the International Co-operation Programme with Mediterranean Partner Countries. The project was entitled *Bases for the Integrated Sustainable Management of Mediterranean Sensitive Coastal Ecosystems.* The acronym MECO takes the initials of the key words, MEditerranean, COasts and ECOsystem, its meaning is thus manifold. Manifold are also the *bases* or perspectives, geographic, geomorphological, biological and socio-economic. The partnership is composed of scientists with different cultural backgrounds and of coastal managers. The partner countries included Italy, Malta, Morocco, Portugal, Tunisia and the United Kingdom. Based on a multidisciplinary starting point, the MECO partnership conducted integrated research. Practical integration was achieved in the field, where scientists with different backgrounds came together and interacted, each taking advantage of the experience of the others.

It was important for this purpose to focus on a few specific study sites. These will be described in detail in the manual (Chapter 2). Their diversity will appear clearly, the choice being not theoretically guided, but dictated by practical reasons. Partners in Morocco, Tunisia and Malta, each proposed one or two local case-study sites, which were of interest for the country, as well as representative of the Mediterranean diversity and issues. In a second phase, integration was practically achieved through meetings in each country, near the study site, where the different baseline studies were discussed and synthesised. The value, weaknesses, potentialities, constraints and management of each study site were studied. A major challenge was the diversity of languages, not only the national languages, which were in great measure shared by the partnership, but by the discipline specific languages. Geographers, geologists, biologists, socio-economists and coastal managers had to explain specific concepts and methods to each other; each participant had to understand other points of view and spatial scales.

The methods, achievements and guidelines developed from the research are presented in this manual and represent a baseline starting point for the sustainable coastal management in the Mediterranean. Managers and policy makers often urgently ask scientists for inputs. Sometimes such inputs take considerable time or are not in a suitable format. Scientific recommendations are not always developed in an easily applicable format for practical implementation. This manual responds to this problem. It has two target readers, coastal managers and scientists willing to contribute to a sustainable coastal management. The manual is also recommended for use in degree and masters courses in coastal management in the Mediterranean region.

The manual starts with a framework section (Chapter 1) to establish key concepts and perspectives. Coastal managers are then taken through practical site characterization (Chapter 2), audits which will be useful in relation to sustainability (Chapter 3), the competencies that will be necessary and, last but not least, what support is available in the Mediterranean to apply the proposed methodology (this information is at the end of each section of Chapter 3 on techniques). Relevant specific concepts are explained in each section. Scientists will learn how different disciplines can contribute to site characterization, audits and identifying indicators of change (Chapters 3 and 4), the type of information coastal managers need to develop management plans and how a management plan is done in practice (Chapter 5). Real examples are used in the manual including specific methodologies used at particular sites; the choice of the concepts presented was dictated by their usefulness; the methods proposed have been proven to achieve useful results.

Diversity is still present in the manual: diversity of languages, points of view and styles of presentation. We are giving to readers a product of the Mediterranean heritage. Such diversity should be the base for future developments and integration. In fact, we hope that this manual is not an end point, but will be the *baseline* for further evolution. Readers are asked to contact us and pose their criticisms and share their different experiences.

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CHAPTER I

FRAMEWORKS FOR PLANNING AND MANAGEMENT FOR SENSITIVE COASTAL AREA ENVIRONMENTS

1.1 PLANNING AND MANAGEMENT FRAMEWORK

Louis F. Cassar and Josienne Vassallo

1.1.1 *Introduction*

Beaches are dynamic coastal environments much dependent on the accumulation of sediments. The availability and subsequent transport and deposition of these sediments, often of sand size and larger, depend on a number of physical factors and processes. These may involve elements such as the geophysical characteristics of the stratigraphy within a given area and the processes of erosion acting upon the rocky exposures that make up nearby headlands and exposed rocky shorelines. Sediment may also originate from nearby beaches in the form of recycled materials, as a result of accelerated erosion. Moreover, seabed topography and bathymetry of the immediate embayment as well as the physical aspect of terrestrial drainage sources, including valley systems and associated watershed, often have a significant influence on beach development.

Depending on the type and source of beach sediments, as well as the existing topography of the coastal region in question, a beach will develop and evolve accordingly. Equally important is land-use. Projects of an infrastructural nature and modifications of the landscape, say for agriculture, have over the years had an impact on coastal regions. This is especially true for sandy beaches with accompanying sand dune sites. Numerous Mediterranean coastal dune sites have suffered degradation and subsequent decline as a result of new infrastructure and development along the littoral, but also much further inland.

Dunes, being dynamic formations, are a prime example of complex and interconnected processes involving geomorphology, including erosion, sediment transport and deposition; hydrological regimes and micro-climate; topography and landscape; sea currents and bathymetry; terrestrial vegetation cover; and land-uses. In particular, land-uses, both on the coast proper as well as in hinterland areas, may affect dunal, as well as beach development in various ways. Perhaps a classic example of a mega-project, which was carried out much further afield of the Mediterranean coast but has significantly influenced an entire coastal region near Alexandria, is the Aswan High Dam construction project. Beach development may be considered a product of the rate of alongshore supply of sediment. Natural interruptions in sediment supply may be spatial, causing displacements of the input sites or changes in the direction of sediment transport, or they may be temporal, that is, related to the sequences of sediment availability at a particular location. Variation in beach sediment budgets may encompass both spatial and temporal changes, thereby increasing the complexity of coastal beach and dunal assemblages.

When considering coastal dune development, the importance of foredunes (that is, that portion of the beach/dune profile that is actively exchanging sediment with the beach) cannot be overstressed. Compared to the vast range of existing dune types, the coastal foredune is a unique morphological assemblage in that it has a restricted spatial association, and is defined by the dynamics which characterize the beach zone as well as the 'traditional' dynamics of aeolian processes that give rise to subsequent dune forms. Coastal foredune development is thus closely related to sediment budget variation in the dune and beach components of the profile.

1.1.2 *Integrated coastal area management*

Sectoral planning as well as narrow and poorly coordinated environmental management practices have induced various environmental problems and often brought about untenable situations. This is especially the case in coastal areas, where the complexity and dynamics that govern such regions are not fully understood and, as a result, mismanaged. Through an integrated approach to environmental management, decisions that pertain to policy and the management of resources can be taken on the basis of long-term goals based on strategic assessment and on the concept of sustainable utilization of resources.

Since environmental concerns cut across interdisciplinary boundaries, it may sometimes be difficult to tackle certain issues without involving specialists from different disciplines (Barrow, 1999). Moreover, some areas are, by their very nature, multidisciplinary. In this respect, therefore, a holistic approach to decision-making and resource management is of paramount importance in view of the complex interactions that involve the land and sea interface within the coastal zone. Thus, Integrated Coastal Area Management (ICAM), which recognises the interconnectedness of coastal regions and aims to provide a strategic approach to planning, may be the appropriate response to balance the demand for coastal resources and resolve conflicts of use. ICAM must be seen as a proactive mechanism that promotes environmental sound technologies that are likely to minimise risk and, where possible, seek to appraise existing problems in their totality (rather than tackle issues in a sectoral manner) through strategic assessment.

ICAM is a continuous and iterative process, designed to promote the sustainable use of resources in coastal areas. Long-term ICAM seeks to balance the socio-economic benefits derived from economic development and human uses. This process involves the integration of objectives and instruments needed to meet these objectives (Commission of the European Communities, 1999; Trumbic and Bjelica, 2001). In principle, ICAM caters for "planning" in its broadest sense, that is, adopting a line towards strategic policy development; and "management" options which comprise the assemblage of information, monitoring and evaluation for review, and implementation. The participation and involvement of key stakeholders in ICAM is a crucial element for any eventual decision-making, especially where trade-offs are concerned.

The development and execution of an ICAM programme can be conducted in a 3-phase approach, involving (i) the initial setting of objectives, (ii) the planning stages, and (iii) implementation (Trumbic and Bjelica, 2001). In applying such method, which stems from the basic steps to plan-making, *i.e.*, "Survey-Analysis-Plan", it needs to be ensured that its focus, on issues pertaining environmental planning and management, is broadened to integrate socio-developmental concerns. For environmental strategies to be implemented with a fair degree of success, in addition to sound technical and economic analysis, an understanding of the nature of the area on which change is being proposed is equally important. This information component is a prerequisite to strategic planning and should precede the stages of *policy-making* and *identification of priority actions*. Successful strategies involve three elements:

- ☐ identifying priority problems
- ☐ defining priority actions
- ☐ ensuring effective implementation

The first phase, therefore, consists of initiation of the process whereby problems and issues are identified and analysed. This is followed by policy formulation and priority-setting as well as budgetary considerations. The second phase shall involve various stages in the planning process, ranging from preliminary planning to site plan analysis and forecasting. Moreover, management goals will be fine-tuned during this phase and strategies improved. The third and final phase involves implementation. This consists of the day-to-day running of the programme and should ensure monitoring and evaluation for subsequent review and revision through adequate feedback mechanisms. Ultimately, an effective Integrated Coastal Area Management programme is facilitated through the active cooperation of key actors and is driven by communication and participation.

1.1.3 *Planning approach*

As discussed earlier, environmental planning and management is not a stand-alone discipline. It is a conglomeration of attributes, which require a fair amount of confluence prior to attempting to 'plan' as it were, using raw facts (data), processed data (information) and available methods for collecting and processing the former two components (techniques). It requires the input of different specialisms, depending on the nature of the changes and activities being proposed. In the case of planning a conservation strategy for coastal areas including beach environments and associated habitats such as sand dunes, it may be said, from the onset, that a *land-use planning* approach would be much too conservative and narrow in scope. A planning method concerned with the natural/rural system as a whole is thought to have a wider scope and therefore be more appropriate, since this would consider the *complexity* and *rationality* and the *re-distributional effects* of the system in its entirety.

The *classic systems* approach, a more conservative view to planning and one which was quite commonly adopted throughout Europe until mid-twentieth century and even later, consists of the breakdown of all known components into categories. In theory, this approach advocates that if one should be capable of describing the 'interest area', then one should be able to plan. However, since the future is unpredictable and uncertain, and considering that there are many other factors, which may overcome plans and predictions, in particular when these relate to the natural environment, habitats or ecosystems, then this approach may prove, in practice, too rigid. Theoretically, there are some elements over which the planner has some control, such as knowledge of major unique locations and constraints on land-use; planners may also influence other variables such as social facilities, land supply policies and, housing and transportation policies. However, in a situation that involves a natural coastal habitat, where ecosystem vulnerability, economic viability and the social fabric must each (individually and holistically) be taken into account, a comprehensive broad-based management approach is deemed most appropriate.

The Mediterranean coastal zone, where, among other important habitats, beaches and sand dunes occur, is a region exposed to a multitude of pressures. At a time when a fair proportion of the region's coast has been taken up by development or is affected by it, and when nature conservation appears to rank highly on national and multilateral agendas, the approach must be two-pronged:

- Goal-oriented (goal-specific)
- Problem-solving (incremental)

Under optimum conditions *System Planning*, a cyclical planning-type process, would probably fit best into the evolution of a 'protected coastal area programme'. However, there is no hard and fast rule as to which planning approach should be considered. Given that the Mediterranean Basin is a region of contrasts, with diverse socio-political and economic opportunities, it may well be the case to amalgamate, say, two modes of planning, for example, *System Monitoring* and *Evolutionary*. Although these, at first, may seem to oppose one another, since System Monitoring tends to advocate a 'minimize change approach' while Evolutionary (a future-oriented mode of planning) is more for stimulating change, the integration of modified planning functions would make different planning modes complementary of one another in a complex coastal zone scenario. Whichever planning mode is adopted, the process may be addressed through a strategic plan, or as an appendage of a national biodiversity strategy, with a view to minimizing constraints, particularly at the implementation level.

The first important steps in environmental planning include *problem identification* and the *setting of priorities*, and subsequently, the *identification of underlying causes*, of which, the identification of underlying causes is crucial to formulating appropriate policies and targeting interventions, and requires an understanding of the link between *cause and effect* of a specific environmental problem affecting coastal habitats. In ideal circumstances this initial phase ought to be followed by the ranking of environmental actions, a process that encourages the maximization of net benefits and involves (i) estimation of control costs; and, (ii) valuation of benefits from conservation actions (Lampietti and Subramanian, 1995). Clearly, a multi-faceted plan must come into play, bringing together nature conservation, the management of natural resources through existing legislation, and the socio-economic requirements of the stakeholders. As much as possible, every effort should be made to seek common ground, although often difficult, among opposing interest groups, since neither nature conservation nor economic activity can be efficiently managed without a certain amount of interaction between the two. Furthermore, the planning process must also consider that land-use priorities of any one site may vary with time and that its potential benefits may be greater in the future. The ideal situation, therefore, would be to apply a fair amount of restraint on development and, in cases where endangered coastal habitats are concerned, decision-makers may even consider placing proposed plans, likely to result in irreversible and large scale land-use change, in abeyance. In other words, it is better to err on the side of caution when in doubt about the possible implications a project may have on the environment. In so doing, the rights of future generations are not compromised!

There is, of course, no single correct way of implementing a strategy, and many possible versions of the above approach exist. The objective is to be pragmatic and incremental - aiming not for perfection but for constant improvement. The accent on participation, in the strategy, cannot be overstressed. This needs to be both wide and deep, involving as many people as possible from all sectors of society.

1.1.4 *Economics of conservation areas*

The dominant economic model in the world today is predicated on the assumptions that national economies and markets must continually grow if humankind is to prosper and progress (Tisdell, 1993), usually at the expense of the natural environment. "The Gross National Product (GNP) is usually considered an adequate measure of this growth even though it does not take into account the loss of natural wealth or quality of life" (Romero, 1993). Such assumptions have led governments of less developed nations to institute unsustainable and exploitative policies, as they endeavour to 'develop' their countries along the same economic model as that of industrialized nations.

Conservationists argue that, aspiring to the levels of consumption (and pollution) of industrialized countries is unattainable and undesirable. The conservation lobby thus advocates a reduced rate of growth as well as national accountability of the 'true' value of natural resources. However, the difficulty with accountability lies in valuing the numerous contributions coastal protected areas make to a national or local economy, since value is generally assessed in monetary terms and not all natural functions and services lend themselves to a monetary value. This is especially the case of cost-benefit analysis (CBA), which demonstrates serious limitations in that, this approach has difficulty in reconciling monetary valuation with social and environmental issues.

1.1.5 *Biodiversity corridors*

In locations where rare or endangered coastal habitat-types are scattered throughout a region and subjected to anthropogenic pressures from unsustainable activities, some form of physical 'contact' between them needs to be ensured. It is widely acknowledged that species preserved in isolation in scattered conservation areas may eventually die out from lack of genetic diversity needed to maintain strong populations. Without the natural dispersal of genetic material afforded by contiguous natural zones, protected species are more vulnerable to effects (natural and human) that could eradicate whole populations.

In an effort to allow communities to adapt to certain changes, the planner, in planning conservation areas programmes, should seek to design *biodiversity corridors* to 'connect' the various habitats so as to ascertain natural genetic dispersal. To ensure that biodiversity corridors are respected, it is not enough to delineate their boundaries and embark on a buffer zone management programme, it is imperative that the cooperation of local resource users is sought. This can only be achieved, long-term, through an intensive environmental education programme coupled by a vigorous wardening system. In the end, conservation area system plans should be the product of informed consensus among all interested parties.

Notwithstanding the fact that coastal habitats need to be afforded adequate conservation measures, foremost to any management plan is the concept that *no protected area is an island*. It must be acknowledged that beach environments are connected to their surroundings in a myriad of ways - ecologically, socially, economically and culturally - and are part of a larger landscape linked to a diverse range of factors that interact with them, and the elements of those linkages are dynamic not static.

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1.2 GEOMORPHOLOGICAL FRAMEWORK

LE CADRE GÉMORPHOLOGIQUE: EPARGNER AUX PLAGES LE DANGER DE L'ÉROSION MARINE

Ameur Oueslati

1.2.1 *Introduction*

Les interventions, dans toute unité naturelle, qui se veulent rationnelles et sans grands risques doivent s'appuyer à une définition précise et rigoureuse ainsi qu'à une très bonne connaissance de la dynamique, de l'histoire et des tendances de l'évolution d'une telle unité. Ces conditions sont d'autant plus impératives que l'unité en question est ouverte et entretient des échanges avec d'autres unités et milieux. Tel est le cas des plages sableuses qui, en plus, sont aujourd'hui particulièrement convoitées par les aménageurs et appelées à affronter une conjoncture difficile à cause notamment du recul de leur budget sédimentaire et de l'élévation du niveau marin prévue pour les prochaines décennies.

Pour parer aux risques que pourrait entraîner une telle conjoncture, notamment l'érosion marine, et aux formes de déséquilibres et de dégradation pouvant résulter des aménagements, les plages doivent être considérées comme étant:

- Des formes qui ne se limitent pas à la seule bande sableuse sur laquelle s'étendent d'habitude les baigneurs;
- Des formes à profils très changeants;
- Des espaces ouverts et dépendants de la dynamique des milieux qui les encadrent;
- Des formes capables de s'adapter aux caprices de la nature.

1.2.2 *Des formes qui ne se limitent pas à la seule bande sableuse sur laquelle s'étendent d'habitude les baigneurs*

Une plage est une forme d'accumulation formée par les vagues, au contact de la mer et de la terre ferme et dont le modelé peut porter l'empreinte d'une activité eolienne importante. Elle a une constitution assez complexe avec trois domaines: l'avant plage, le bas de plage et le haut de plage (Fig. 1.2.1).

Ce dernier correspond généralement à un bourrelet appelé aussi dune bordière ou avant-dune. Son développement est, en partie, favorisé par des plantes adaptées à l'environnement littoral et capables de fixer le sable poussé par le vent depuis le bas de plage.

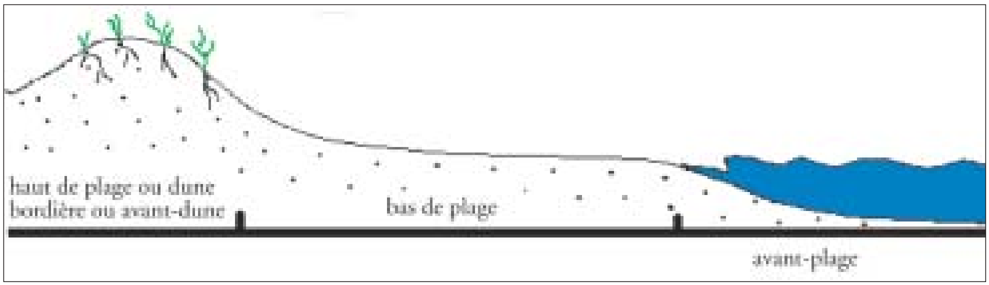

FIG. 1.2.1 *Les grandes subdivisions d'une plage sableuse*

1.2.3 *Des formes à profils très changeants*

Si le spécialiste de la géomorphologie littorale insiste sur la trilogie "avant plage, bas de plage et dune bordière" c'est parce que ces domaines sont très complémentaires et solidaires l'un de l'autre. Ceci apparaît en particulier à travers les échanges sédimentaires qui s'y opèrent (Fig. 1.2.2) et qui constituent pour la plage un moyen d'autodéfense lors des moments difficiles. Ces échanges témoignent, en même temps, du rôle capital de réserve en sédiments que peut jouer la dune bordière et du caractère jamais définitif du profil de la plage.

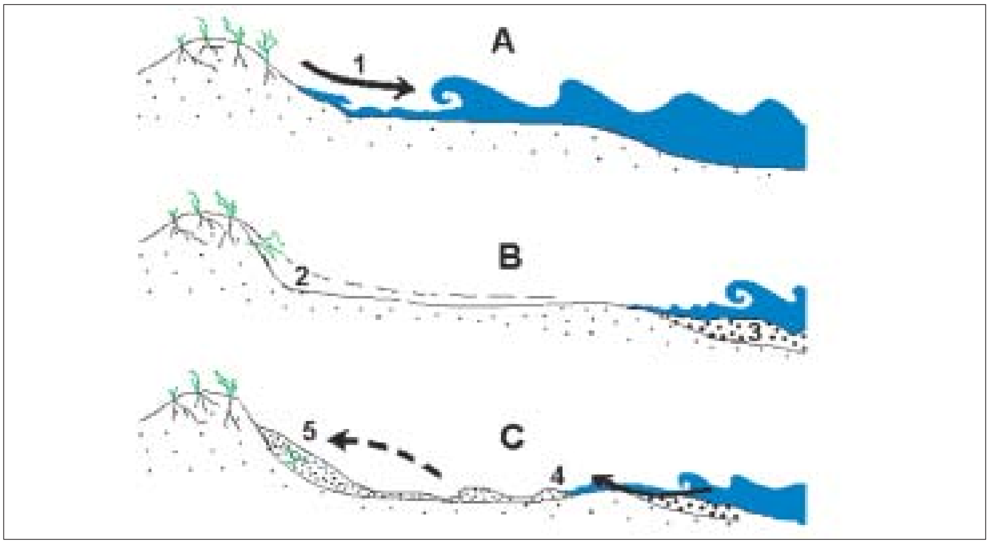

FIG. 1.2.2 *Une plage évoluant à l'état naturel: En* **A**, *début de la saison des tempêtes, les vagues envahissent le bas de plage et atteignent la dune bordière et commencent à leur arracher du sable (1). En* **B**, *le matériel arraché (2) est l'accumulé dans le domaine de l'avant plage; une barre (3) se forme entraînant un affaiblissement de la profondeur des eaux et oblige les vagues à briser à des distances de plus en plus éloignées de la ligne de rivage. Ainsi, bas et haut de plage échappent progressivement à l'attaque directe des vagues déferlantes. En* **C**, *au cours de la belle saison l'évolution inverse se produit; les sédiments accumulés dans l'avant plage sont restitués au bas de plage par les vagues (4) puis au haut de plage par le vent (5)*

Si bien qu’une plage peut, tant qu’elle évolue à l’état naturel et que sa dynamique n’est pas perturbée, être entamée par les vagues et montrer des signes d’érosion à la suite des tempêtes mais tout se corrige pendant la belle saison (Fig. 1.2.2).

Perturber cette dynamique conduit souvent à exposer la plage à une érosion qui peut finir, parfois dans un laps de temps court, par entraîner sa disparition. Le danger vient très souvent des constructions de front de mer qui empiètent sur une partie du bas de plage et sur l’avant-dune (Fig.1.2.3). Les eaux qui les heurtent deviennent plus agitées, se retirent avec une vitesse accélérée emportant avec elles plus de sable que d’habitude: un déséquilibre sédimentaire naît et l’érosion l’emporte: c’est le début d’un cycle interminable de destruction par les vagues et de tentatives de protection par l’homme. Ce cycle commence souvent avec une grande tempête.

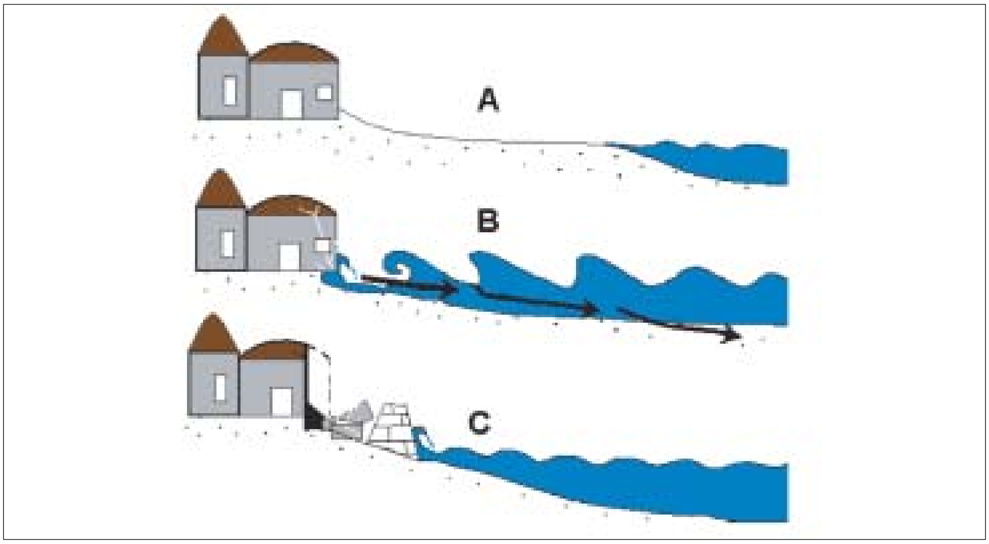

FIG. 1.2.3 *Une plage dont la partie interne a été envahie par des constructions* (**A**)*: Les eaux qui s'avancent vers le haut de plage à l'occasion des tempêtes* (**B**) *trouvent à leur rencontre des structures qui favorisent leur agitation et accentuent le pouvoir érosif et déséquilibre sédimentaire. Avec le temps, l'étendue sableuse qui sépare les constructions de la mer disparaît. Même les constructions peuvent être menacées, ce qui oblige le recours à des travaux de défense* (**C**)*. Ici, le moyen utilisé est un mur de front de mer mais dans des côtes densément aménagées on peut rencontrer une variété d'ouvrages parfois lourds, très coûteux et dégradants pour le paysage (enrochements, épis, brise-lames, ...)*

1.2.4 *Des espaces ouverts et dépendants de la dynamique des milieux qui les encadrent*

Les plages entretiennent, par l’intermédiaire des courants marins, le vent et les eaux courantes des interactions multiples avec les segments côtiers voisins ainsi qu’avec l’avant-côte et l’arrière-pays (Fig. 1.2.4).

Ceci influence largement les caractéristiques de leur budget sédimentaire; paramètre fondamental dont la connaissance aide beaucoup à comprendre leur capacité à faire face aux moments difficiles: la situation devient critique si ce budget devient déficitaire, c'est à dire, lorsque la plage perd plus qu'elle ne gagne.

Précisons également que la largeur d'une plage n'est pas l'unique ni toujours le meilleur indicateur de ce budget et que toute plage étendue n'est pas forcément à l'abri de l'érosion. Car il faut aussi tenir compte de l'épaisseur de cette plage ainsi que de la nature des interactions qu'elle entretient avec son environnement et l'impact des modifications qu'elle risque de connaître suite aux aménagements existants ou programmés ou aux changements d'ordre naturel.

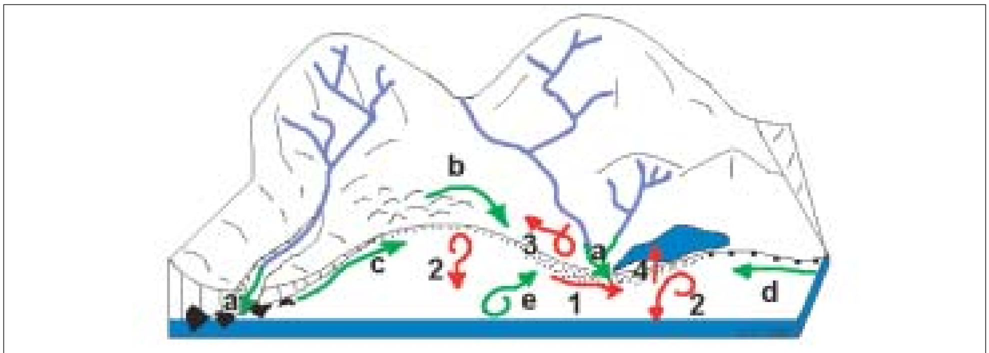

FIG. 1.2.4 *La plage reçoit des sédiments par les cours d'eau* (**a**)*, par le vent* (**b**)*, par les courants côtiers longitudinaux depuis des falaises* (**c**) *ou des côtes rocheuses basses* (**d**) *et par les vagues et les courants marins depuis le large* (**e**)*. Elle perd des sédiments par les courants côtiers longitudinaux* (**1**)*, par des courants marins dirigés vers le large* (**2**)*, par le vent* (**3**) *et par les vagues de tempêtes qui la franchissent et atteignent des terres déprimées ou des lagunes* (**4**).
Toute intervention susceptible d'entraîner des modifications dans ces échanges (ports, barrages sur les cours d'eau exoréiques, obstacles contre le vent,…) ou une limitation de la production sédimentaire dans les milieux de départ (stabilisation du bassin-versant, pollution des eaux marines, pertubation des formes de vie dans la mer comme par certaines pratiques de pêche,…) peut avoir des conséquences sur le budget sédimentaire de la plage et donc sur son évolution, son modelé et sa capacité à faire face à l'action des vagues

1.2.5 *Des formes capables de s'adapter aux caprices de la nature*

On a vu que les plages peuvent, grâce aux échanges sédimentaires qui s'opèrent à travers leur profil transversal, s'adapter aux différents états de la mer. Mais seraient-elles en mesure de faire face à l'élévation du niveau de la mer, de quelques décimètres au moins, prévue pour la fin du XXI^{ème} siècle et qui, par ses effets (notamment le retrait des rivages et la salinisation des terres), est considérée comme l'une des menaces les plus sérieuses pour les côtes basses, surtout celles faites de roches tendres et qui ne reçoivent pas des apports sédimentaires en quantité suffisantes pour repousser la mer ?

En fait, les plages, même si elles figurent parmi les formes les plus sensibles à une telle élévation, ne seront pas toujours condamnées à disparaître (Fig.1.2.5). Elles peu-

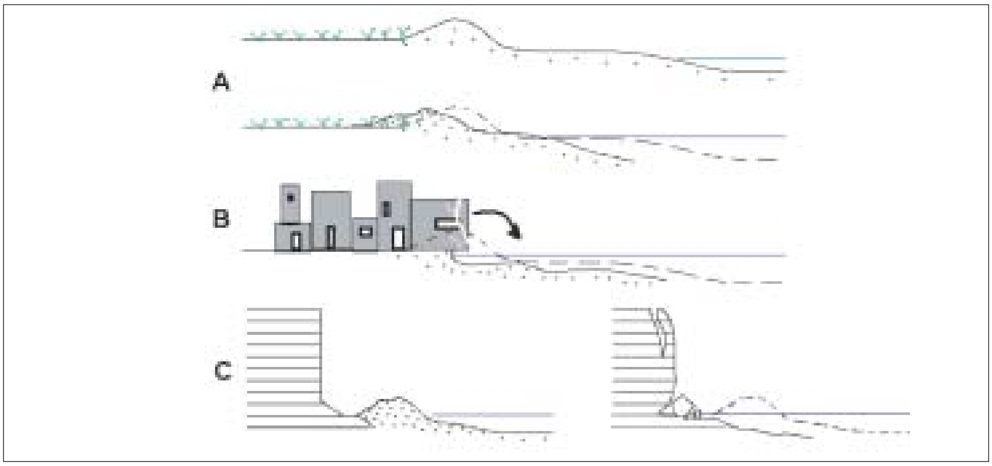

FIG. 1.2.5 *Dans une conjoncture favorable à l'avance de la mer à cause d'un affaiblissement du stock sédimentaire des estrans ou d'une tendance du niveau marin à monter par exemple, les plages ne sont pas forcément condamnées à disparaître. Elles migrent en direction du continent* (**A**). *Les problèmes commencent lorsque cette migration se trouve perturbée ou handicapée par des obstacles d'origine anthropique* (**B**) *ou naturelle* (**C**)

vent continuer à exister et sont capables de s'adapter à la nouvelle situation en migrant en direction du continent: en roulant sur elles-mêmes à la manière d'un tapis roulant. Les problèmes commencent dès que cette adaptation se trouve handicapée ou devient impossible à cause d'un affaiblissement du budget sédimentaire et surtout à cause de l'existence d'un obstacle en front de mer qui s'oppose à la migration. Celui-ci peut être naturel (un escarpement par exemple) ou artificiel (des constructions surtout). La place est alors donnée aux formes d'érosion et de destruction.

D'où tout l'intérêt qu'ont les aménagements côtier à tenir compte de cette éventuelle élévation du niveau de la mer au moment de la définition de la distance que les aménagements ou même les délimitations du Domaine Publique Maritime (D.P.M.) doivent garder par rapport à la mer (Fig. 1.2.6).

1.2.6 *De quelles informations a-t-on besoin?*

Ainsi, pour épargner aux plages et aux infrastructures qu'elles peuvent attirer les formes de dégradation et les dangers de l'érosion marine, les plans d'aménagement doivent s'appuyer à des informations précises sur:
– **le cadre météo-marin** avec en particulier une bonne connaissance des événements exceptionnels comme les grandes tempêtes. Car c'est à l'occasion de tels événements que la mer s'avance le plus en direction des parties internes de la plage et que se produisent les modifications les plus spectaculaires dans le profil de ce dernier et les dégâts les plus catastrophiques dans les aménagements de front de mer,
– **la dynamique de la plage** au cours des différentes périodes de l'année, ses réac-

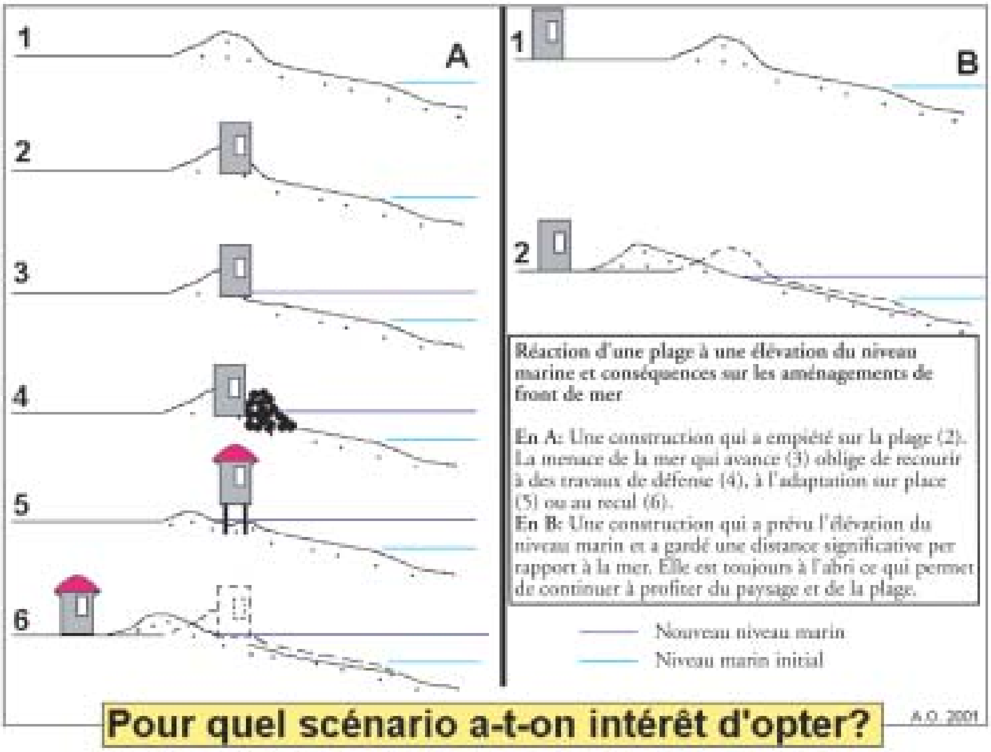

FIG. 1.2.6 *Réaction d'une plage à une élevation du niveau marin et conséquences sur les aménagements de front de mer*

tions aux données météo-marines et surtout les modifications qui affectent aussi bien son profil transversal que l'épaisseur de ses sédiments; données à travers lesquelles se dégagent formes d'adaptation et d'autodéfense face aux agents en action. Des mesures et des relevés répétés sur le profil de la plage, directement sur le terrain et sur des périodes significatives, constituent le meilleur moyen pour comprendre cette dynamique,

– **le budget sédimentaire** de la plage en considérant les aménagements, entrepris ou programmés (barrages, ports, destructions d'herbiers par la pêche ou la pollution, travaux de protection dans les segments côtiers voisins,...) qui sont susceptibles de l'influencer et pourtant d'entraîner des modifications dans la dynamique marine et la position du rivage. La définition de la distance à garder par rapport à la mer par exemple, doit tenir compte, entre autres paramètres, de la réaction de ce budget sédimentaire à de tels aménagements,...

Exemples: Des constructions implantées sur une plage privée des apports sédimentaires depuis le continent ou depuis des segments côtiers voisins par exemple (suite à la construction d'un grand barrage sur le cours d'eau qui y débouche ou l'aménagement d'un port), ne tarderont pas à se trouver en difficulté. Au contraire des constructions implantées du côté de la face, exposée à la dérive littorale principale, d'un ouvrage s'avançant en mer (jetée d'un port, épi,...) verront leur plage s'élargir (Fig. 1.2.7).

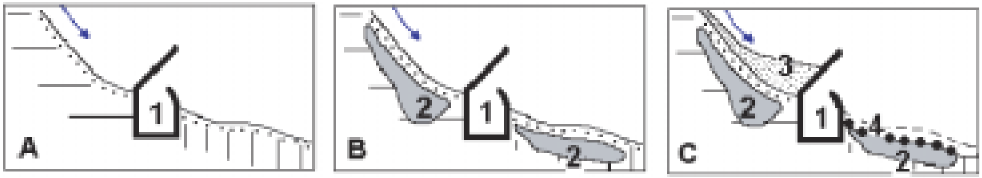

FIG. 1.2.7 *Schéma classique des effets d'un aménagement portuaire et d'une multiplication des constructions à très peu de distance du rivage sur l'évolution de la plage dans une côte à dérive littorale active (indiquée par la flèche) portant vers une direction préférentielle:* (1) *port;* (2) *constructions;* (3) *plage élargie;* (4) *plage érodée (le trait discontinu indique l'ancienne position du rivage);* (4) *travaux de protection*

L'implantation d'une borne de D.P.M. du côté de la face qui tourne le dos à la dérive littorale principale d'un obstacle qui s'avance en mer risque d'être sans intérêt si elle ne tient pas compte du déplacement du rivage que peut provoquer cet obstacle,…

– **la fréquentation humaine** (intensité et mode) dans l'objectif de définir la capacité de charge de la plage. Une telle capacité peut être définie en partant de la superficie de la plage mais elle doit tenir compte aussi de la sensibilité de la faune et de la flore associées à son matériel. Ceci exige, outre l'observation répétée et des mesures directes sur le terrain, des enquêtes auprès des utilisateurs de la plage (estivants, occupants des constructions de front de mer,…),
– **l'histoire récente de l'environnement côtier: une approche rétrospective** peut aider sérieusement, en permettant de mieux comprendre les tendances de l'évolution la plage, à mieux définir les aptitudes à l'aménagement. Cette tâche oblige le recours à différents documents: archives variées (textes, photos,…) et surtout à des observations minutieuses du terrain (modelés de détail, mesures répétées sous des conditions météo-marines différentes, recherches de traces significatives pour l'évolution et exploitation de tout repère pouvant éclairer sur la mobilité de la ligne de rivage à commencer par les traces des anciennes variations du niveau marin et des vestiges archéologiques jusqu'aux aménagements modernes,
– **les prévisions relatives à l'évolution future du milieu naturel: l'approche prospective** est désormais indispensable. Elle permet des réflexions fructueuses quant à la réaction de la plage aux modifications, d'ordre naturel (l'élévation du niveau marin par exemple) ou anthropique, prévues dans l'avenir.

Des informations significatives concernant ces différents points peuvent autoriser des modélisations et aider à mieux construire les scénarios d'aménagement.

1.3 BIOLOGICAL FRAMEWORK

1.3.1 *Introduction* (Felicita Scapini)

Some activities, particularly those involving high number of people, such as tourism, are likely to impact ecosystems, particularly when these are as fragile and limited in space as are sandy-pocket beaches. Biologists are then asked to characterise and estimate the *biological value* of a particular area with a view to management. Decision makers should take these estimates into account to preserve the natural heritage for the benefit of the local population, the country and the whole region, including a concern for the future generations. Eco-audits are thus necessary to monitor changes in biological value and the sustainability of the management. This volume presents some techniques for measuring diversity at different levels, from communities of different organisms and single species populations, to the level of the individual genome (Chapter 3). Here the relevant concepts of diversity and biodiversity are discussed, to clarify what should be measured and why.

Biodiversity is the most important concept in this context, and includes different levels of integration, from the ecosystem to the genes. It reflects the complexity of the different life forms and their interactions with the environment, both physical and biological. The more diverse the elements in an ecosystem, the more complex the existing interactions and the less sensitive (*i.e.* more buffered) against changes it will be. Sandy beaches are generally characterised by few abundant species, and the forcing factors are mainly physical (Brown and McLachlan, 1990; McLachlan, 2000). This is particularly true for the littoral zone where soft sediment is subject to rapid dehydration by direct sun light on the one hand, and is continuously influenced by wave and tidal action on the other. This zone is not colonised by plants, and those animals living there depend on imported organic material of both marine and terrestrial origin. This explains the abundance of individuals and biomass of the few species which are to be found here. Neighbouring zones, namely the sand dunes and the river mouths, are characterised by their instability and sensitivity (Section 1.2). However, they often contain valuable and rare ecosystems, and discontinuities between some coastal zones may give rise to islands of biodiversity, even if they are not physically separated from the mainland.

Managers need to develop strategies which conserve the uniqueness of many sandy beach ecosystems, taking into account the high sensitivity of these natural environments.

1.3.2 *Diversity and Biodiversity* (João C. Marques)

Statisticians are generally unhappy with the diversity concept. The main reason for this might be the dynamics of diversity, which is permanently changing the information content, representing therefore a trouble in any set of definable probabilities. In fact, is basically impossible to stabilise variance in samples, since the entire model suffers from the typically irregular dynamic changes almost always found in nature. Such dynamics combines a general tendency to increase diversity through different processes, with the occurrence of unexpected periods of decline, which are often spatially extensive. Therefore, although diversity can be measured, it can hardly be considered as a static property of samples proceeding from a given system.

Attempts have been made to discriminate between two components of diversity, *i.e.*, the number of species in presence (species richness) and the uneven representation of the different species (eveness). Nevertheless, these two components are correlated, since they emerge from an artificial division of the same distribution pattern, produced by our minds, and therefore it can be argued that there is no reason why we should expect any clear advantage from such approach.

Another approach is represented by the "rarefaction methods" or extrapolation procedures, which seek for estimating an "expected number of species". Nevertheless, the statistical properties in the natural sets assumed by such methods, although interesting, are not proved, and therefore they cannot be recommended.

Even one of the simplest ways to express diversity, the rank frequency diagrams (Frontier, 1985) may be criticised, namely when certain features of the sequences, like "convexities" or "concavities" are interpreted as an effect of prevailing biological interactions. Although this might be possible, the most probable, and perhaps more realistic, explanation for such characteristics is that the initial conditions of the average pattern may simply reflect transient population oscillations affecting the species living concurrently in a given community. On the other hand, this constitutes an interesting starting point regarding the issue of seasonal variation and its irreversibility.

An additional problem in estimating diversity must be examined. It lies on the fact that modular organisms, for instance large marine macrophytes or macroalgae, cause difficulties in defining and counting individual organisms as such. Consequently, it becomes much more complicated to estimate diversity when we deal with systems that combine big vegetal species or colonial animals with isolated individuals, often belonging to a great number of different size strata. In such cases, to perform estimations based on biomass provides only a partial solution. In fact, modular species are of great importance, namely because they behave as quite conservative genetic pools. In other words, nature is too complex to be successfully described by simple indices, and all the tries proposing new ways to estimate diversity couldn't provide any tangible conceptual progress.

This more than brief synopsis provides an approximate idea of the difficulties involved in understanding the dynamics of diversity. Therefore, it is not pessimistic if we say that there is no conceivable "diversity index" capable of expressing the dynamics of mixed populations, exhibiting stabilised values through space and time. The difficulties may be summarised as follows:

a) The increase of diversity through time is inevitably gradual, more often than not associated with the emergence and transformation of an organised system, but the decrease of diversity is most frequently abrupt.
b) Looking to the spatial characteristics of ecosystems, we are forced to conclude that it is impossible to have stabilised variance, which may lead us to favour any kind of spectral expression taking into account the way diversity may shift as a function of the space considered. The problem in this case is that each spatial enlargement provides a different spectrum as a function of the characteristics of new sites added to the sample.
c) Since the biosphere is a continuous, it is not adequate to set apart "local" diversity (called α diversity) from diversity estimated by pooling discontinuous patches (β diversity) or measured at larger spatial scales (γ diversity), although, in a certain extent, such description might become helpful to approach the biodiversity concept.

We may say that, at present, biologists give less emphasis to the interpretation of diversity as an indicator regarding representative segments of the biosphere. Instead, the interest turned into "biodiversity". This new term emerged suddenly by the end of the eighties in the past century, and its use expanded rapidly. Although it is still difficult to say where this new concept came from, biodiversity is, beyond any doubt, much more "saleable" and therefore much more appealing to decision-makers. But let's appraise if the novelty restricts only to this "marketing" idea.

To some authors biodiversity may be seen as the full range of biological diversity from intraspecific genetic variation to the species richness, connectivity and spatial arrangement of entire ecosystems at a landscape level scale. This means that biodiversity concerns much less the existing numerical proportions among different taxonomic units and much more the absolute number of such taxonomic units or, in other words, genetic richness. In this sense, biodiversity represents a more holistic approach to ecosystem's properties than the old diversity concept.

The biodiversity concept becomes especially interesting with regard to high diversity ecosystems, where the two properties, in their ultimate form, are not necessarily related with higher biological or metabolic activities, rather the contrary. A good example of this is the profuse biological diversity in deep sea benthic environments, where the major driving force behind diversity development is the balance between the energy flow, usually expressed in turnover, and the genetic differentiation related with a hard survival in such environment.

Although more holistic, the biodiversity concept is indeed relatively simple, which allowed to relieve the pressure concerning quantitative measures that prevailed for many years following the more conventional concept of diversity. On the other hand, such different perspective emphasised the goal of finding simple and comprehensive regularities that may relate the total number of species found in samples with environmental changes at smaller (local) scales through speciation, migration, and extinction processes. So to say, the previous diversity concept gave origin to biodiversity, which finally helped in making more precise his meaning. In fact, somehow, through years of use, the old concept of diversity had been side tracked to a kind of static statistical problem, which in fact it is not since it finally expresses the dynamics of ecosystems as a whole. On the other hand, the emphasis on biodiversity allowed revitalising taxonomic studies (this was most probably one of the ideas behind the shift in concepts) and provides a better tool to assist the analysis of the structure and dynamics of the biosphere. The relations between the two concepts are therefore significant and may be described in an elegant way if we assume that Diversity develops from the stores of Biodiversity.

An example may illustrate even better the relations between the concepts of diversity and biodiversity as they generally used. It is well known that, independently from the local diversity regarding marine plankton communities, plankton blooms associated with upwelling, which usually develop successively or in different places, concern only a few species. This is in many aspects similar to what we described with regard to cyclic changes in temperate terrestrial and aquatic ecosystems. Since in biodiversity we include the reserve of genotypes, such marine plankton blooms may be interpreted as "experiments in evolution" which borrow genotypes from the reserve of biodiversity, play with it and, genetically changed or unchanged, return it back to the general store. The major interest of ecologists is typically focused on the most active segments of the yearly spectrum, associated with moderate or high biological activity, here referred as "experiments in evolution". From this perspective, it might be suggested that in temperate regions we should usually find a significant difference between actual diversity and total potential (bio)diversity, while for instance in equatorial climates, where seasonal variations are meaningless, the difference between diversity and biodiversity should be not so large.

To look upon biodiversity as a dynamic reserve containing a fraction of the results from past evolutionary processes, acting as a genetic information pool and providing the potential substratum for existent diversity is quite helpful in enlightening the relations between the two concepts (see Fig. 1.3.1). In accordance with this perspective, ecosystems should continuously accede to genetic materials from the biodiversity store, and natural selection should act upon their active expression. In case any new valuable genetic acquisition occurs, eventually new information provided by the reworked materials returns to the biodiversity store, enriching it. On the other hand, through time, the parts of the biodiversity store that have less and less actual active expression should become obsolescent and eventually disappear, together with much larger fractions of information that are removed as a result of major environmental changes, *e.g.* orogenic processes, climatic change, or human impacts. Events taking place in the active parts of ecosystems are forcibly constrained within limits that depend on the biodiversity store, and must be seen as "experiments in evolution" that provide a rather important loop, necessary to understand the reciprocal relations between the complementary concepts of diversity and biodiversity.

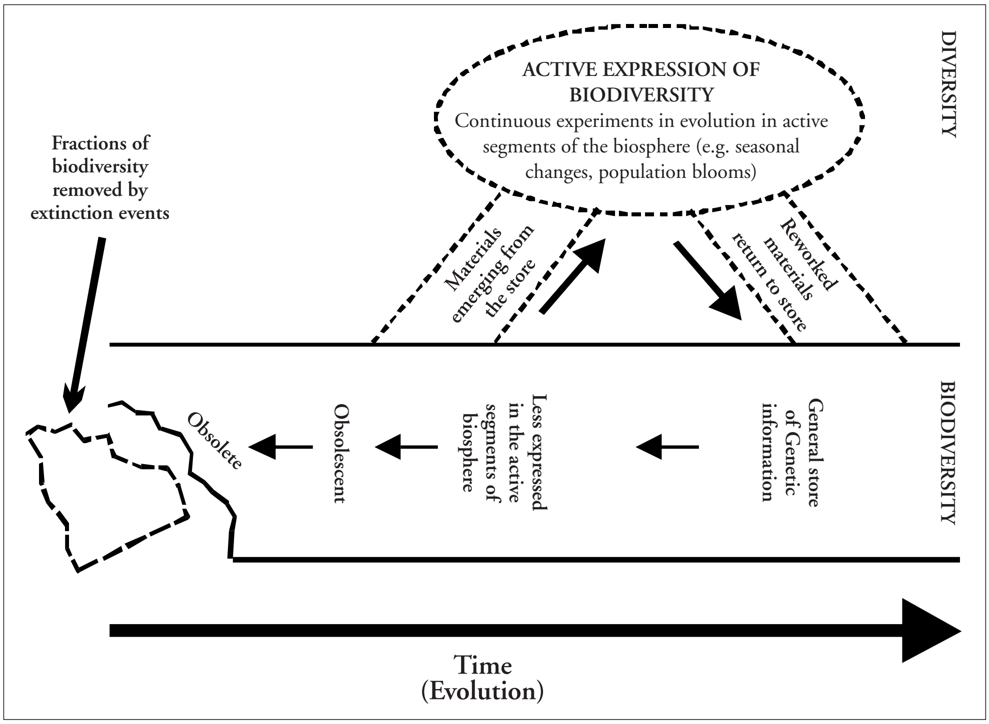

FIG. 1.3.1 *Tentative scheme describing the relations between diversity and biodiversity*

1.3.3 *References*

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1.4 SOCIO-ECONOMIC FRAMEWORK

A FRAMEWORK FOR THE ANALYSIS OF SOCIO-ECONOMIC IMPACTS ON BEACH ENVIRONMENTS

Alison Caffyn, Bob Prosser and Guy Jobbins

1.4.1 *Human impacts*

The coast is a dynamic environment subject to physical change caused by geomorphological, oceanographic, meteorological and biological processes. However, over history human impacts on coastal areas have increased enormously. Around the globe a high proportion of human activity and development has taken place at the coast because of the concentration of resources in coastal areas and the need for transportation. Many major cities and ports are located on the coast along with many industrial and tourist developments. 50-70% of humans live within 60 km of the coast and this proportion is increasing.

The following diagram (Fig. 1.4.1) introduces the wide range of impacts human activity may have on beach and coastal environments. It is not exhaustive, but usefully summarises landward and seaward issues and the types of general impacts, which may be experienced by coastal areas.

Coastal management has to respond to a wide range of pressures and conflicts. There is increasing competition for coastal resources and increasing conflicts between resource users. This has often resulted in environmental degradation or pollution, particularly of sensitive ecosystems such as estuaries, mangroves, salt marshes and coral reefs. This section focuses on the socio-economic impacts of human activity, particularly on beach environments.

Beaches have been the focus for much human activity throughout history. They have been valued economically for resources such as fishing, shell fisheries, bait digging, seaweed harvesting and sand extraction. But beaches also have great social and cultural significance as places of escape and relaxation (Lencek and Bosker, 1999). They are places where people can get away from the pressures of urban life and can relax and 'recreate' with friends and family.

As people had access to more free time, beaches became increasingly desirable locations for holidays. Gomez and Rebollo (1995) date the construction of the beach in Europe as a social product to the mid eighteenth century. Beaches were initially perceived as places for healing and many spa towns developed such as San Sebastien, Dieppe and Brighton. Later in the late nineteenth and early twentieth century the emphasis changed to leisure and fashion for social élites, in locations such as the

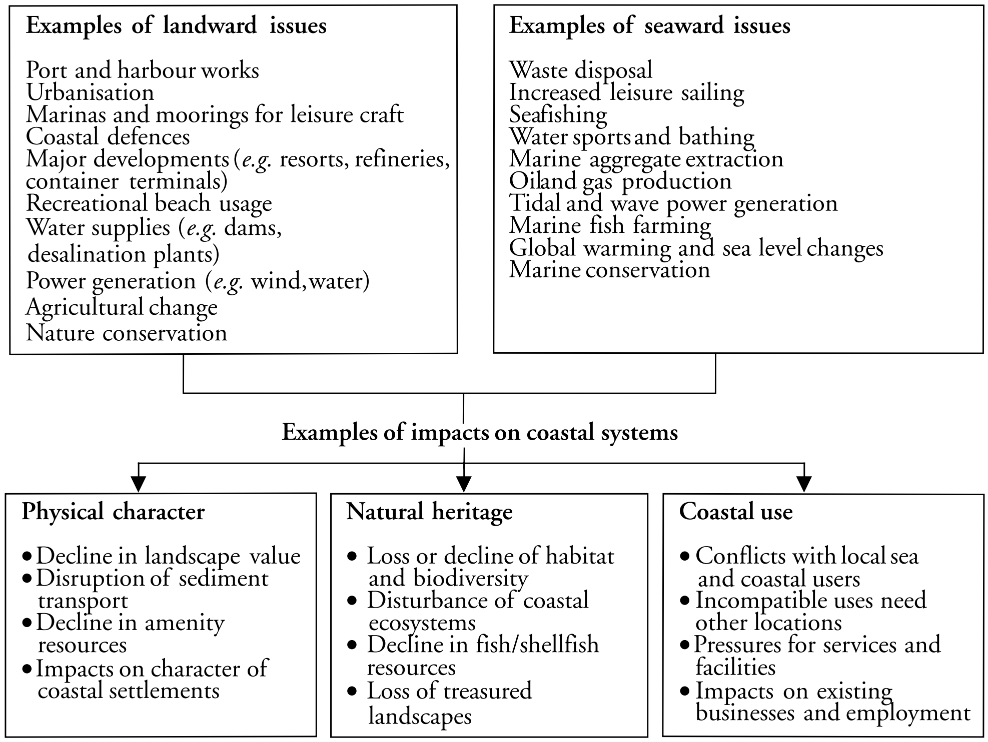

FIG. 1.4.1 *Examples of human impacts on coastal environments (adapted from UK Local Government Management Board 1995)*

French Riviera. Since the 1950s beach tourism has grown at an enormous rate and has become a mass phenomenon. Many cultures have become attracted by the package of sun, sea and sand offered at beach resort locations. Over 200 million tourists visit the Mediterranean every year, 80% to the European Union countries (Montanari, 1995). Many small Mediterranean fishing villages have been transformed into major resorts *e.g.* Torremolinos in Spain. It is estimated that in the western part of the north Mediterranean coast over 75% of the dune systems have been destroyed (Gehu, 1985 cited in Udo de Haes and Wolters, 1992).

These developments have brought significant economic and social impacts as well as physical transformations. Impacts can be both positive and negative and include:
– business growth and investment;
– economic diversification and modernisation;
– decline of traditional economic sectors;
– revenue and tax generation;
– increased employment opportunities;
– loss of, or commodification of, traditional cultures;
– changing social mores;
– changes in the status of women;
– urbanisation and increased property prices;
– modernisation of infrastructure and services;

– education and training opportunities;
– importation of goods and employees;
– indirect impacts on other economic sectors;
– increasing external influence of large businesses;
– elements of globalisation.

Much has been written about the impacts of tourism (Mathieson and Wall, 1982; Inskeep, 1991; Ritchie and Goeldner, 1994); it is sufficient here to summarise key elements and to focus on an integrative framework for analysing and managing these impacts in beach environments. The impacts of tourism and recreation can be particularly acute on coastal ecosystems, the resources of which are often exploited or impacted upon well beyond their tolerance threshold.

A key concept is **environmental quality**. Many socio-economic uses of beaches are dependent on the good quality of the beach environment. In particular, once the environment begins to degrade and be damaged it will be less attractive for visitors and tourists. Thus if the water is polluted, or there is a large quantity of litter, or the beach sand is seriously eroded, people may seek alternative sites. This tendency for tourists to move on to newer, pristine destinations is well known. Gomez and Rebollo (1995) identify the need to restructure mass coastal tourism and develop a new model of the coastal tourism product both because of environmental degradation but also because tourist markets are becoming tired of mass coastal products. They suggest either major improvements in the quality of existing mass tourism or the creation of new high quality areas which are better integrated into the environment and provide good infrastructure and service. Montanari (1995) identifies a shift from beach tourism to cultural tourism, including visits to natural areas, archaeological sites and historic cities and agritourism.

Beach visitors are increasingly demanding good quality facilities such as toilets, parking, life guards, refreshments, beach umbrellas, showers, etc. Thus, a fundamental task for managers is to provide the facilities which are necessary for the type and volume of visitor but also to preserve the quality of the environment.

Quality itself is a difficult concept. It relates to customer satisfaction with the product or service provided not necessarily to certain measures. Thus it is important to understand the consumers and what standards they expect in order to provide a quality product and experience. In the case of beach environments the quality of facilities and services such as lifeguards will be important as well as the physical environment. The challenge for managers at destinations is to encourage visitors to come again and to maintain sustainable visitor numbers. Recent management initiatives have focused on quality management as the key concept in developing more sustainable forms of tourism and recreation (European Commission, 1999). Managers need to maintain or improve the quality of the environments and of related facilities and services to continue to attract visitors.

1.4.2 *Physical impacts on beach environments*

The physical impacts of human activity and hence their socio-economic implications vary greatly depending on the type of environment and the type and level of usage (Table 1.4.1, Fig. 1.4.2). Physical impacts may be categorised into the following four categories:

1. Direct impacts of people on the beach;
2. Impacts on the water environment;
3. Impacts of infrastructure;
4. Impacts of management techniques.

TAB. 1.4.1 *Examples of physical impacts of human activity on beach environments*

DIRECT IMPACTS OF PEOPLE ON THE BEACH	IMPACTS ON THE WATER ENVIRONMENT	IMPACTS OF INFRASTRUCTURE	IMPACTS OF MANAGEMENT TECHNIQUES
Trampling of vegetation	Waste and sewage discharge from boats	Construction of permanent buildings	Construction of groynes, coastal defences, fences, barriers
Disturbance of wildlife	Petrol/oil pollution	Temporary buildings, structures, caravan sites etc.	Beach cleaning
Erosion of dunes and beach	Damage to sea floor from anchors	Illegal buildings and structures	Grazing regimes
Litter (including debris from fishing activities)	Poor fishing methods	Construction of marina, jetties	Forestry management
Human and dog waste	Scuba diving = damage to coral etc	Construction of roads, parking and paths	Water extraction
Fires/barbecues Vehicle damage, including mobile kiosks	Water disturbance	Demand for water and energy Toilets and showers	Waste and sewage management systems Management of fisheries
Damage to beach from digging, boat launching		Loss of habitat	Enforcement of planning regulations
Disturbance and erosion from horse riding		Installation of bins, safety equipment, umbrella	Dune stabilisation

It is important also to look for indirect impacts which may occur as a consequence of direct impacts.

One of the most significant impacts in many areas is the consumption of drinking water. Montanari (1995) gives figures for normal water consumption rates of people in less developed countries – between 18 and 36 m^3 a year, and in more developed countries – between 90-180 m^3 a year. However tourist in luxury hotels may consume as much as 0.6-1 m^3 *a day*, placing severe pressures on water supplies.

Fig. 1.4.2 *Examples of human impacts from the MECO sites, Smir (Morocco), Kneiss (Tunisia) and Armier Bay (Malta).* (**A**) *At Smir temporary buildings are erected each summer season as cafes. The number is regulated through permits.* (**B**) *Permanent constructions, also at Smir, cause more serious impacts.* (**C**) *At Kneiss there were serious impacts from the fishing techniques local fishers used.* (**D**) *Armier, where illegally sited caravans caused problems. Some were removed by the Planning Authority in 2001*

In addition the type of governance system will also have impacts on the way a beach environment is used and managed. The governance system will affect:

– decision making - how decisions are made and by whom;
– power relationships - which stakeholders hold most power and how it is used;
– local involvement - how and to what extent local communities and stakeholders are involved in planning and management;
– allocation of funding.

1.4.3 *An integrative framework for analysis*

It is important to take a holistic approach and to analyse and address as many elements as possible in designing methods for monitoring, planning and management. There is a need for integration both horizontally (between different sectors and types of impacts) and vertically (between local, regional and national issues and responses). The following table (Tab. 1.4.2) adds to the previous discussion by incorporating the socio-cultural and economic dimensions. Examples of issues in each sector are identified in terms of the value of beach environments, the impacts of human activity, infrastructure, management regimes and how governance systems influence each sector.

TAB. 1.4.2 *Integrative framework for issues to be considered*

	ENVIRONMENTAL ISSUES	SOCIO-CULTURAL ISSUES	ECONOMIC ISSUES
Value (local-national scale)	Valuable environment and ecosystems	Attraction of beach environments - enjoyment	Fishing, recreation and tourism
Impacts of human activity (local scale)	Trampling, erosion, pollution	Recreation and relaxation	Revenue, seasonality
Impacts of infrastructure/facilities (local-regional scale)	Construction, habitat loss, barriers and erosion	Quality and range of facilities	Businesses and employment
Impacts of management regime (local-regional scale)	Beach cleaning, water supply	Cleanliness, safety aspects	Economic viability, wider linkages to other sectors
Influence of governance system (regional-national scale)	Environment, resources and development planning	Health, education, social development	Economic development and tourism development

1.4.4 *Key issues of socio-economic impacts*

a. *Issues of scale*

It is important to consider issues of scale when examining impacts. Some human activities will have localised impacts (such as litter), others will affect a much wider area (such as employment of people from the local area or the construction of a dam). Other aspects such as governance systems affect beach management at a national or even international scale. The photos (Fig. 1.4.3) and table (1.4.3) in next page illustrate this with examples of small scale and large scale human impacts.

b. *Stakeholders*

For a socio-economic analysis it is essential to identify all stakeholders or stakeholder groups who have an interest in the beach environment being studied. A stakeholder is someone who has an interest or stake in the site. This could be someone who owns, uses or simply values the site as important. Stakeholders include:

- Owners;
- Local and national government;
- Management agencies;
- Local businesses *e.g.* fishing, tourism, recreation, others;
- Local residents;
- Visitors;
- Conservation groups;
- Voluntary organisations;
- Scientific community.

There may be very different views both between stakeholder groups and within them. Local residents will not necessarily all have the same opinions and government

FIG. 1.4.3 *Examples of small and large scale impacts from the MECO sites, Smir (Morocco) and Zouara (Tunisia).* (**A**) *Vehicles driven on the beach, here at Smir, disturb the sand, vegetation and biota (Carter, 1988: 493).* (**B**) *The construction of a dam, here at Zouara, has major impacts on the sediment supply to the beach*

TAB. 1.4.3 *Examples of small and large scale human impacts*

SCALE	ISSUE
Beach sub zones	Patterns of human usage, litter, localised impacts
Whole beach	Location of facilities, safety issues
Immediate hinterland	Parking, visitor management, local environment
Local area	Business development and employment, social impacts
Sub region	Wider economic impacts, water resource issues
Region	Impacts on regional economy, regional co-operation in management
Country	Governance systems and management systems

agencies may also disagree. Some users will use the site more regularly than others and some will have much better knowledge of the site than others. It is important to analyse all stakeholders and to try to identify their views and needs when developing a management plan. This will improve the plan as it will address a comprehensive range of issues. In turn, it is likely to be more successful as all the stakeholders will feel involved and are more likely to comply with any management recommendations (Goodhead and Johnson, 1996).

Methods for stakeholder analysis and identifying local views are discussed in chapter 4. The diagram of Fig. 1.4.4 illustrates the basic stakeholder relationships for Zouara as an example. Again it is important to consider stakeholders at all scales - local, regional and national.

In some places a Local Agenda 21 project has been used to try to involve all stakeholders in developing a sustainable strategy for the management of a destination. An interesting example in a well developed tourism destination is Calvia in Mallorca, Spain (Calvia, 1999). Local people and businesses are invited to become actively involved in identifying priorities and in developing management strategies.

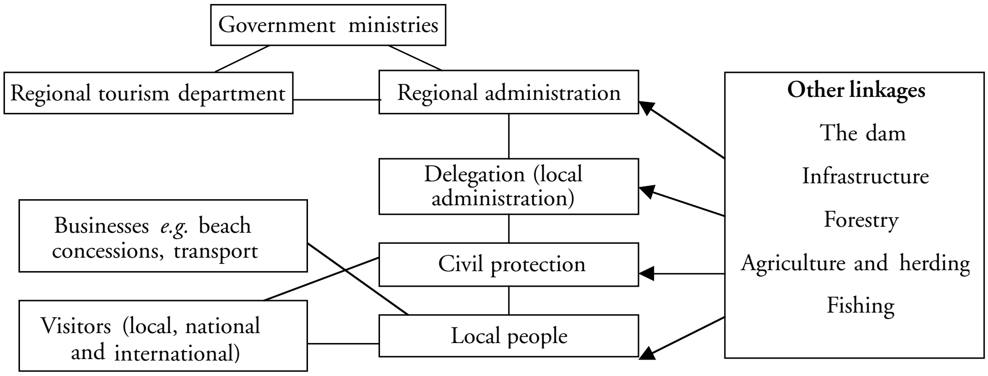

FIG. 1.4.4 *Stakeholders at Zouara, Tunisia*

c. *Levels of development*

Of course some beaches are much more developed than others in terms of recreation and tourism facilities. Calvia, mentioned above, is a mature destination including resorts such as Magalluf and Palma Nova, developed in the 1950s and 1960s. The beach and resort environments are very different from Zouara in Tunisia where there has been very little development and most facilities provided are temporary structures (Fig. 1.4.5). It is important to assess the level of development of any site at an early stage. In Malta, Morocco and Tunisia there are both well developed, mature beaches and lesser developed areas. The sites studied during the MECO project represent different points on a continuum of development:

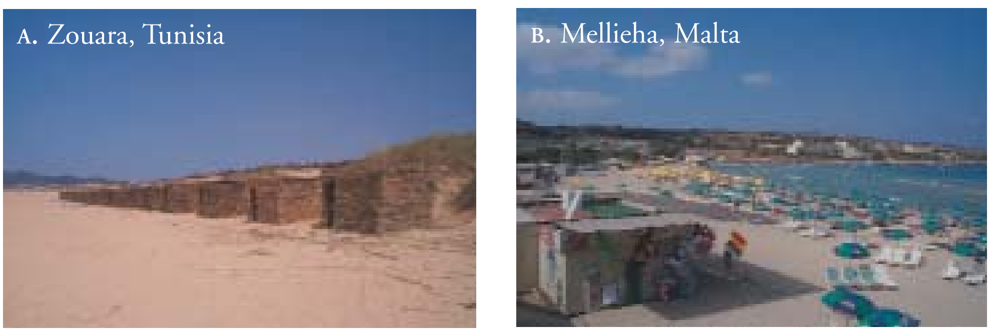

FIG. 1.4.5 *Examples of temporary* (A) *and permanent* (B) *structures at the MECO sites*

Beaches at different levels of development tend to attract different types of visitors in search of different types of experience (De Ruyck *et al.*, 1995), although accessibility and socio-economic factors are also important.

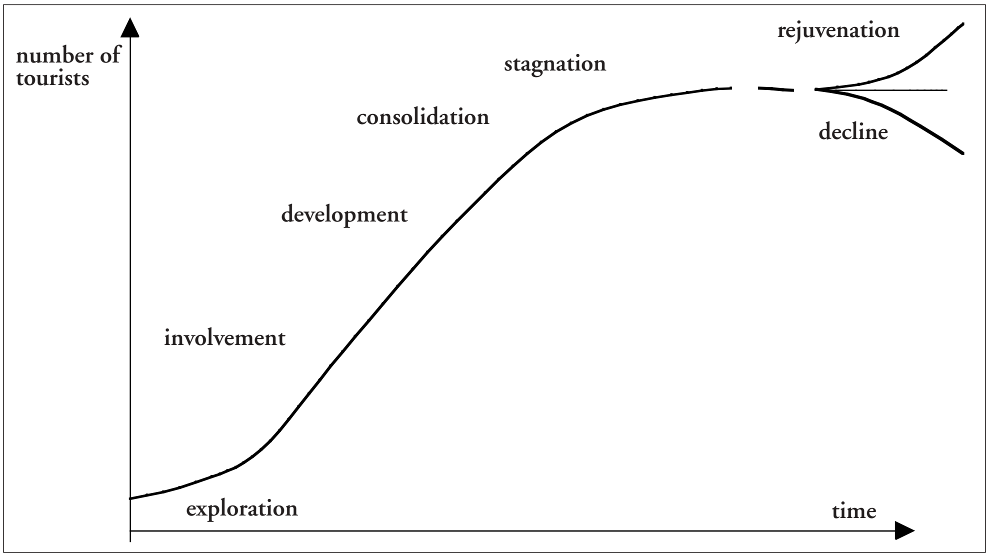

FIG. 1.4.6 *The tourist area life cycle model*

Another way of considering level of development is through the well known model of the tourist area life cycle (Butler, 1980). This presents a model of evolution through which it is hypothesised most tourist destinations will move over time (Fig. 1.4.6).

The model, while over simplified, is a useful way of demonstrating the challenges managers face as a destination becomes more developed and visitor numbers increase, particularly as it focuses on change. When applied to a beach environment the development would be in the form of increasing facilities which may in turn then attract more visitors. The model suggests that there may come a point when the beach is overdeveloped and damaged and may potentially decline not just environmentally but also economically.

In fact managers should consider focusing investment on more developed beaches and maintain others as undeveloped or less developed to offer choice to visitors with different preferences. This implies halting the life cycle before the development stage in these cases.

d. *Seasonality*

Many socio-economic activities and particularly tourism, are seasonal in nature. In some destinations the tourist season is only a few months long and this has negative impacts on the economy and employment. Managers should take this into account and in most cases plan to spread the season through more of the year by attracting different types of tourism or other activities. For example sport tourism or birdwatching are likely to be in the spring and autumn months and therefore be complementary to summer sun tourism. Other aspects of seasonality include the peak demand for water being when supplies are at their lowest. Also labour demand may peak in summer which is often the peak period of demand for agricultural employment.

1.4.5 *Key concepts for planning and management*

a. *Carrying capacity*

The concept of carrying capacity has been used to try to address concerns about the levels of development and use of sites. This concept implies that there is a number of people which a particular site can accommodate without significant damage but that once this capacity is reached there will be both a reduction in the quality of the environment and also visitors' experiences will suffer (Innskeep, 1991, Coccossis and Parpairis, 1996).

The idea of carrying capacity can also be applied to social aspects of tourism development. Doxey modelled community attitudes towards tourism as it develops over time (Doxey, 1975 cited in Kay and Alder, 1999). In his Irridex model local people firstly feel *euphoria* when tourism starts, as there are opportunities to make money and meet people from other areas/countries. Early tourists are often keen to meet local people and learn about local cultures as compared with the types of tourist who take part in mass tourism. However as the industry expands tourists are taken for granted, local people feel *apathy* and personal contact becomes more formal. Later as facilities expand, big companies take over and tourism begins to encroach on the local people lives, they feel *irritation.* This can develop into *antagonism* as mass tourism grows and tourists may become the target of frustration and anger of local people who feel excluded and their local environment damaged. This implies that there is also a social carrying capacity which is the level at which the local community feels it can happily accommodate the number of visitors.

Social carrying capacity can also be estimated for beach users as the level at which visitors begin to feel overcrowded. However this level has been found to vary between gregarious types and more individualistic types of visitor who desired less developed beaches and lower densities of people (De Ruyck *et al.*, 1997).

The concept of carrying capacity, whether environmental, social or an economic capacity, has been difficult to apply in practice. Some destinations do apply a limit on the number of visitors, for example, by using a permit system. Once the set number of people have visited (per day/month/year) then no more are allowed in. Another method would be to limit the size of car parks. However identifying the correct level and establishing and implementing such a management system is difficult (Williams, 1994).There will be different capacities for different uses. Physical, social or economic capacities are likely to be at different levels. It interferes with people's freedom to visit locations and usually implies they will be charged for their permit. De Ruyck *et al.* (1995) found that proposals to limit beach access were unpopular with the public.

b. *Limits of acceptable change*

A more flexible concept has become popular which focuses on the levels of change in the physical and socio-economic environments which would be seen as acceptable by most stakeholders. This approach is called limits of acceptable change (LAC). It aims to involve stakeholders in deciding what management and conservation methods are necessary. The approach involves a series of key stages:

1. Broad review of issues in the area;
2. Description/characterization of conditions in the area;
3. Identification of change and indicators of change;
4. Survey of indicators of change;
5. Specification of quality standards;
6. Prescription of desired conditions in each zone;
7. Agreement of management action to maintain quality in each zone;
8. Review of proposals for area as a whole;
9. Implementation, monitoring and review.

(Sidaway, 1995: 310)

The advantages of this approach are that instead of taking a negative approach such as trying to identify a carrying capacity, it focuses on a positive approach of managing for quality. It incorporates a rational planning approach which focuses on desirable future conditions (Sidaway, 1995). It also focuses on *change*. Identifying key indicators of change is a crucial part of developing and monitoring a management strategy. Methodologies for identifying and integrating indicators are discussed in chapter 4. LAC is likely to work best when stakeholders are involved as this will improve acceptance and support for management methods.

c. *Recreation Opportunity Spectrum*

One of the difficulties in planning and management for recreation and tourism uses is that different people want to use the area in different ways. Some are happy just to sit on the beach while others want to walk, play games, swim, take part in water sports, fish etc. Some people like busy beaches, others like peace and quiet and want to get away from the crowd. Here the concept of a recreation opportunity spectrum (ROS) is useful. It can be used alongside the limits of acceptable change concept in planning and management for socio-economic uses of beaches both at the local and regional scale.

With ROS recreation is considered in terms of settings and experiences desired by various users, not just facilities or activities. A range of opportunities is identified to meet most users' demands. Settings and experiences take place in environments identified as pristine; semi-pristine; semi-modern and modern, depending on their level of development, road provision and access arrangements. Settings combine physical, biological, social and managerial conditions. By varying these conditions managers can provide a range of experiences, varying from getting away from the crowds in a natural setting with no support facilities to a modern resort development (Pigram and Jenkins, 1999). Thus managers can combine and balance conservation and recreation goals.

Recreation Opportunity Spectrum and management factors

Recreation settings and experiences

primitive — semiprimitive — semi modern — modern

Pristine environment ⟷ Intensively managed environment

Management factors include:

- Access – how to get there, distance from nearest town, type of roads, parking location and capacity;
- Non recreational resources uses – such as mining, forestry, energy generation or power lines;
- Onsite management modification – facilities, designated walks, complexity and visual impact of management;
- Social interaction – level of contact with other people, groups;
- Acceptability of visitor impacts – degree and spread of impacts;
- Acceptable regimentation – visitor management, regulations, safety measures.
  (Adapted from Pigram and Jenkins, 1999 and Kay and Alder, 1999)

d. *Principles for an approach to sustainable tourism*

The final concept which is outlined in this section relates specifically to tourism development. There has been an enormous amount written in the last ten years about how to develop more sustainable forms of tourism which have reduced negative impacts on environments and cultures. There is no room to discuss the concept and its limitations here, but it is useful to identify a set of key principles which managers may be able to incorporate in management strategies. One of the most useful sets of principles developed to date is that by Bramwell *et al.* (1998) based on an analysis of the sustainable tourism literature.

Principles behind the approach to sustainable tourism:

1. The approach sees policy, planning and management as appropriate and, indeed, essential responses to the problems of natural and human resource misuse in tourism.
2. The approach is generally not anti-growth, but it emphasises that there are limitations to growth and that tourism must be managed within these limits.
3. Long-term rather than short term thinking is necessary.
4. The concerns of sustainable tourism management are not just environmental, but are also economic, social, cultural, political and managerial.
5. The approach emphasises the importance of satisfying human needs and aspirations, which entails a prominent concern for equity and fairness.
6. All stakeholders need to be consulted and empowered in decision making, and they also need to be informed about sustainable development issues.
7. While sustainable development should be a goal for all policies and actions, putting the ideas of sustainable tourism into practice means recognising that in reality there are often limits to what will be acheived in the short and medium term.
8. An understanding of how market economies operate, of the cultures and management procedures of private sector businesses and of public and voluntary sector organisations, and of the values and attitudes of the public is necessary in order to turn good intentions into practical measures.
9. There are frequently conflicts of interest over the use of resources, which means that in practice trade-offs and compromises may be necessary.
10. The balancing of costs and benefits in decisions on different courses of action must extend to considering how much different individuals and groups will gain or lose.

e. *Summary*

All of these concepts may be difficult to apply in practice. However it should be possible for managers in many locations to adopt and incorporate key elements as basic planning and management principles. These key elements include:

- Complete a comprehensive audit of current use and impact;
- Identify impacts of people, of infrastructure, of management techniques and of governance systems;
- Integrate environmental, social and economic elements;
- Consider issues of scale and level of development;
- Involve stakeholders;
- Incorporate quality management;
- Identify indicators of change;
- Consider recreation settings and experience.

Levels of tourism in the Mediterranean are predicted to continue increasing at a rate of between 2 and 4% per year and it is likely that there will be increasing pressure on areas that are currently less developed (Grenon and Batisse, 1989). Other sectors such as fishing, water resources, port developments, industrial developments and mineral extraction are also exerting increasing impacts on coasts. Coastal managers face many challenges in developing responses.

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CHAPTER 2

PRESENTATION AND CHARACTERIZATION OF THE SITES

2.1 LE SITE DE ZOUARA
TUNISIE

2.1.1 *Présentation morphologique* (Ameur Oueslati)

a. Une plage étendue

L'une des plus étendues de la Tunisie, la plage de Zouara est aussi l'une des plus exposées aux vents forts des secteurs septentrionaux et appartient à un segment côtier connu pour la fréquence et la violence de ses tempêtes, surtout au cours de la saison hivernale.

Sa morphologie associe un bas de plage large de quelques décamètres à plus de 100 m (au droit de Oued Zouara) et un bourrelet de haut de plage ou avant-dune, haut en moyenne de 4 à 8 m et à tracé très rectiligne, en fait contrôlé par des travaux de fixation du sable. Quant à l'avant-côte, il se caractérise par un modelé de sillons et de rides sableuses souvent épaisses et bien marquées.

Cette abondance sédimentaire s'explique d'abord par les apports de Oued Zouara qui prend source dans des terrains accidentés, évoluant par ravinement et mouvements de terrains et à ossature géologique dominée par le flysch numidien qui par ses épais bancs de grès favorise la libération et le départ du sable. Elle s'explique également par l'arrivée des matériaux poussés par les courants côtiers depuis les falaises vives des segments côtiers voisins, largement taillées dans des roches gréseuses.

b. Un champ dunaire à morphologie variée et complexe

De forme triangulaire et s'avançant sur plusieurs kilomètres à l'intérieur des terres, ce champs est l'un des plus étendus sur les côtes tunisiennes (Fig. 2.1.1).

L'activité éolienne y a été étroitement influencée ou guidée par la topographie locale. Sur les surfaces régulières ou peu accidentées, elle a donné lieu à des accumulations du type nebka de tailles variées isolées ou appartenant à des crêtes parfois continues sur plusieurs hectomètres, voire sur quelques kilomètres. Dans ce dernier cas, le sable couvre souvent des crêtes gréseuses plus anciennes. Les couloirs ont, en canalisant les masses d'air, servi surtout de voies de transit pour le sable. Par contre, sur les versants relativement escarpés les accumulations sont généralement épaisses et montrent un aspect de surface massif à nombreuses rides transversales.

c. Des repères pour la reconstitution de l'histoire de l'homme et des paysages ainsi que pour la connaissance des tendances récentes de l'évolution de l'environnement

Vaste, le champs dunaire a, en plus de l'activité éolienne, connu l'intervention de

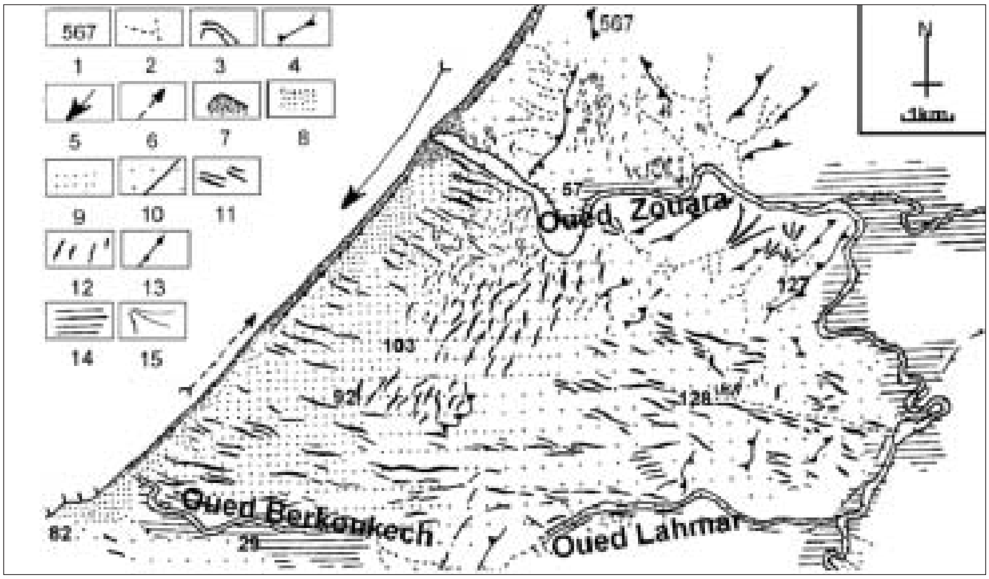

FIG. 2.1.1 *Morphologie du champ dunaire de Zouara:* (1) *point côté;* (2) *oued secondaire;* (3) *oued principal; berge montrant souvent des terrasses alluviales;* (4) *ressaut structural (souvent grès numidien);* (5) *dérive littorale principale;* (6) *dérive littorale secondaire;* (7) *plage;* (8) *éolianites affleurant au milieu de dunes vives;* (9) *dunes meubles recouvrant des éolianites et épousant souvent leur modelés;* (10) *dunes s'avançant à contre-pente; dunes ayant franchi la première ligne de crête du relief côtier;* (11) *crêtes de unes longitudinales;* (12) *crêtes de dunes transversales;* (13) *cordon de haut de plage formé grâce à des travaux de fixation du sable;* (14) *alluvions et terrasses alluviales récentes;* (15) *cône de déjection largement formé par du sable poussé par le ruissellement depuis le champs dunaire*

différents agents morphogéniques, notamment les eaux courantes, et a commencé à être fréquenté par l'homme très tôt.

Les dunes appartiennent à plusieurs générations qu'on peut classer, par leur faciès, dans deux grands ensembles: des dunes consolidées (éolianites) d'une part et des dunes meubles d'autre part. De plus, dans chacun de ses ensembles s'intercalent des dépôts ruisselés et des sols peu épais mais très significatifs car ils indiquent que la mise en place du champ dunaire ne s'est pas faite de façon continue et que l'action des eaux courantes l'a parfois emporté sur celle du vent sans doute à la suite de variations dans les caractéristiques du climat et du niveau marin. L'écho de telles discontinuités ou ralentissements dans l'activité éolienne existe aussi sous la forme de terrasses alluviales emboîtées ou étagées visibles dans la partie aval du cours de Oued Zouara ainsi que dans les petits cours d'eau qui traversent les dunes.

Les traces de la présence de l'homme s'échelonnent sur une période relativement longue allant de la préhistoire à l'Antiquité et sont matérialisées par:
- une industrie lithique de facture moustéroïde à atérienne. On la trouve en surface ou remaniée dans le matériel de la terrasse alluviale la plus haute et à la surface des dunes consolidées formées à l'occasion des variations du niveau marin qui ont

marqué le Quaternaire supérieur surtout le dernier interglaciaire (Tyrrhénien); les traces de stationnement de la mer à des altitudes supérieures à celles du rivage actuel existent dans les falaises des segments côtiers voisins (du côté de Cap Negro par exemple),
– une industrie épipaléolithique héritée des civilisations ibéromaurusienne et néolithique parfois associée aux niveaux inférieurs des dunes meubles et des colluvions qui les séparent ou qui s'y intercalent,
– des ruines antiques dont les plus étendues sont enterrées sous le sable des dunes meubles.

Les traces de l'homme préhistoriques existent en de nombreux endroits, parfois sous la forme de jonchées étendues d'artefacts taillés dans différents matériaux (silex et grès surtout). Elles apparaissent et disparaissent au gré de la mobilité du sable.
Les ruines antiques les plus importantes, par leur extension, existent dans le secteur de Argoub El Bania, sur la rive droite de Oued Zouara, immédiatement en aval du barrage. Elles sont presque entièrement enterrées sous les dunes. On peut se demander s'il ne peut pas s'agir des témoins d'un ancien comptoir établi à côté d'un port ou d'un abri important pour barques. Celui-ci se situerait au niveau de l'embouchure de Oued Zouara immédiatement en aval de la digue du barrage. Il aurait été remblayé pour laisser la place à l'épaisse plage qui caractérise le site de nos jours.

d. Une plage en moins bon état qu'il y a quelques décennies et à risques dans l'avenir

Si le champ dunaire n'a cessé de perdre sa vivacité sur le plan géomorphologique, à cause surtout des travaux de reboisement qui ont fixé le sable, la plage est appelée à faire face à une dynamique plus intense et surtout à une nouvelle conjoncture qui ne lui sera pas toujours favorable.

Le rivage échappe encore aux formes de dégradation, notamment les problèmes dus à l'érosion marine, dont souffrent bien de rivages sableux en Tunisie et en Méditerranée. Les figures d'érosion qu'on peut y rencontrer au cours de la saison hivernale, comme les microfalaises taillées dans le matériel du bas de plage, ne doivent pas être prises pour des signes d'une tendance au démaigrissement. Elles font partie d'une dynamique classique dans les plages sableuses (Fig. 2.1.2). L'oeuvre des tempêtes hivernales, elles disparaissent pendant la belle saison.

La plage serait cependant en moins bon état qu'il y a quelques décennies et risque, en tout cas, de se trouver face à des difficultés dans l'avenir:
– Elle est en moins bon état à cause d'une réduction des apports terrigènes suite à la multiplication des obstacles sur le chemin des eaux courantes (routes, travaux de C.E.S., …) mais aussi suite aux grands travaux de reboisement. La forêt a des effets bénéfiques indiscutables pour l'environnement mais elle a, en fixant les dunes, contribué à dérégler une dynamique naturelle qui permettait à la plage de retrouver, par le vent qui souffle depuis le continent et surtout par les eaux courantes, une partie du sable qu'elle perd par le vent. Ce rapatriement s'inscrivait dans un cycle du sable original: le sable soufflé par le vent s'avance en direction du continent jusqu'à ce qu'il rencontre un cours d'eau qui le ramène à la mer. En

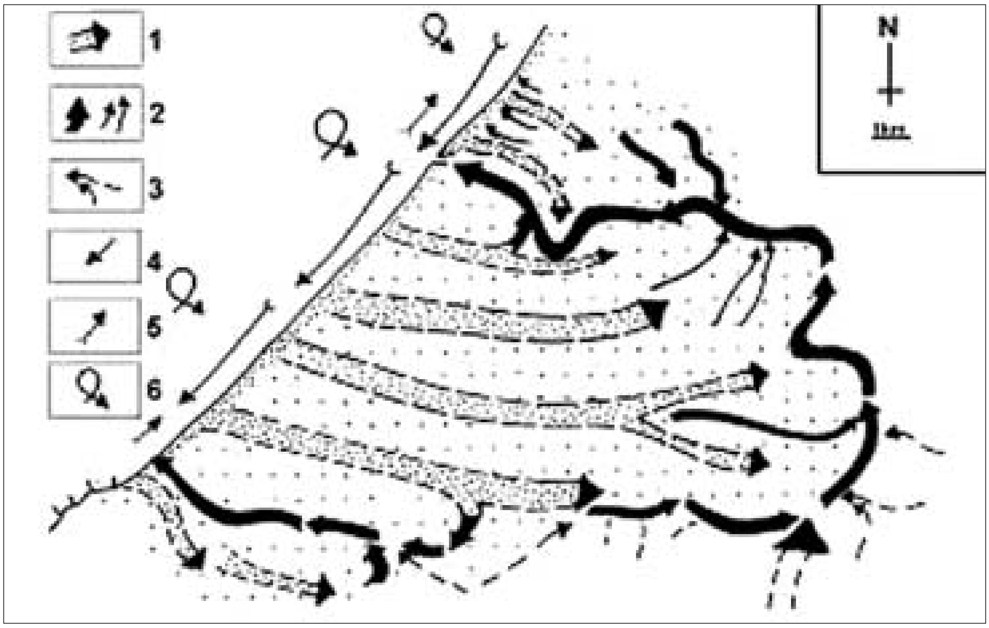

FIG. 2.1.2 *Représentation schématique du cycle du sable dans le secteur de Zouara:* (1) *sable poussé par le vent depuis le rivage;* (2) *sable poussé par les eaux courantes depuis le champ dunaire pour être rapatrié à la plage;* (3) *alimentation par les eaux courantes à partir des reliefs voisins;* (4) *dérive littorale principale;* (5) *apport sédimentaire depuis le large*

effet, la limite interne du champs dunaire est largement définie par le dessin du réseau hydrographique. Oued Lahmar par exemple, a toujours constitué une limite infranchissable pour les dunes. D'ailleurs, il doit son nom au sable qui tapisse sa berge gauche et son lit: Lahmar signifie en arabe rouge en faisant allusion à la couleur du sable.

– A risques puisqu'elle risque de se trouver face à des difficultés à cause de l'implantation du barrage de Sidi El Barrak. Car, en plus des termes de l'écosystème et du paysage qui vont connaître inéluctablement des modifications, cet ouvrage important aura comme conséquence une accentuation de la réduction de la fourniture sédimentaire dont profitait la plage.

Aussi, l'approche géomorphologique apporte-t-elle des indications qui, considérées dans un plan d'aménagement, peuvent aider à mieux valoriser les potentialités naturelles et patrimoniales et surtout d'éviter les conséquences, parfois dramatiques comme on en voit dans plusieurs rivages sableux, des interventions imprévoyantes.

e. On insistera en particulier sur:

– **La qualité du paysage naturel:** le site et ses environs offrent une richesse intéressante en paysages favorisée par la juxtaposition de topographies contrastées et de géologies variées: rivage sableux et dunes étendues coincés entre la mer et les versants escarpés de la chaîne montagneuse des Khmirs. Cette variété est enrichie par un réseau hydrographique assez développé et un couvert végétal relativement important.

– **Les potentialités en patrimoine géologique et archéologique:** la variété morphologique, la diversité des formations géologiques et l'existence de vestiges de plusieurs civilisations sont autant d'atouts pour la région. Outre leur grande valeur patrimoniale, elles constituent des repères très importants pour la connaissance de l'histoire de l'homme et des paysages ainsi que pour la reconstitution des paléoenvironnements, la compréhension des tendances de l'évolution et de la dynamique du milieu naturel et de la réaction de ses composantes aux mutations qui ont pu affecter la dynamique des agents en action au cours des temps récents. Or ceci, en plus de sa grande importance sur le plan scientifique, procure des informations permettant une base plus solide pour la définition des aptitudes de ce milieu à l'aménagement.
– **L'extrême vulnérabilité du patrimoine:** d'une part, les coupes géologiques sont souvent peu développées en épaisseur et accordent une grande place aux matériaux tendres. Si bien qu'elles peuvent être facilement détruites. Une attention particulière doit leur être accordée, surtout celles qui renferment des vestiges d'anciennes civilisations humaines qui leur donne une valeur double: géologique et archéologique.
  D'autre part, les différentes traces humaines sont souvent enfouies dans le sable et ne sont pas toujours faciles à identifier. Ceci s'applique surtout aux industries lithiques qui, au gré de la mobilité du sable, sont enterrées ou mises au jour. Des interventions non averties peuvent facilement entraîner leur disparition.
– **Le suivi de l'évolution du rivage notamment au droit du barrage de Sidi El Barrak:** ce barrage qui vient d'être mis en service aura, en plus des conséquences sur les écosystèmes et les paysages, un impact sur le budget sédimentaire de la plage. Un travail de suivi est indispensable; c'est en fait une occasion remarquable donnée pour mettre sur pied un observatoire qui permettra de mieux comprendre la dynamique et l'évolution de ce milieu et surtout la réaction de ses constituants et des agents qui y interviennent aux modifications apportées.
– **La préservation de la plage des aménagements de front de mer:** malgré sa largeur la plage de Zouara doit être gardée à l'abri des aménagements et des formes d'occupation de nature à dérégler sa dynamique naturelle. On pense en particulier aux constructions en dur qui accentuent l'agitation des eaux marines lors des tempêtes et s'opposent aux échanges sédimentaires qui s'opèrent entre les différentes parties du profil transversal de la plage. Ces précautions sont d'autant plus impératives que cette plage risque de voir son budget sédimentaire diminué du fait de la construction du barrage.
– **Les dunes en tant que réserve sédimentaire:** outre leur importance pour le paysage et les écosystèmes, ces dunes doivent être considérées comme une réserve sédimentaire et une gage de sécurité pour les moments difficiles que connaîtrait la plage.
  Ceci est important dans une conjoncture marquée par le retrait des rivages et la menace d'une élévation du niveau marin et à un moment où on pense de plus en plus à la défense douce pour les plages menacées de démaigrissement. Le rechargement artificiel, l'une des pratiques les plus conseillées, exige du sable en grandes quantités et à caractéristiques sédimentologiques adaptées à la plage qu'on veut recharger. Dans le cas de la plage de Zouara il s'agira d'un simple rapatriement de matière puisque le sable des dunes provient de la plage.

FIG. 2.1.3 *Diversité paysagère à Zouara.* (**A**) *Plage étendue et de bonne qualité;* (**B**) *Forêt naturelle diversifiée;* (**C**) *Ruines antiques presque enterrée sous les dunes;* (**D**) *Collecte de l'Ammophila*

2.1.2 *Présentation biologique* (Faouzia Charfi)

La région de Zouara présente une remarquable diversité paysagère avec une plage sableuse, bordée par un champ dunaire des plus vastes rencontrés sur les côtes tunisiennes (Fig. 2.1.3). Dans l'immense forêt bordant le complexe des dunes de sable, on peut reconnaître une forêt de reboisement constituée soit par des plantations homogènes de pin pignon (*Pinus pinaster*), soit par des étendues essentiellement à base d'*Acacia* parsemées par des pieds épars de retam (*Retama sphaerocarpa*), de laurier rose (*Nerium oleander*) dans les lits des cours d'eau et de rares pieds de genévrier de Phénicie (*Juniperus phœnicea*) et une forêt naturelle dominée par le chêne kermès (*Quercus coccifera*), le genévrier oxycèdre (*Juniperus oxycedra*), le genévrier de Phénicie, le filaire (*Phyllirea angustifolia*), le lentisque (*Pistacia lentiscus*), etc. Cette forêt naturelle se trouve à l'ouest de la zone de Zouara, en direction de Tabarka. A l'est de la zone, se trouve l'Oued Zouara sur lequel a été édifié le barrage de Sidi ElBarrak (Fig. 1.4.3 B).

Ces différents milieux forment des écosystèmes variés, plus ou moins diversifiés et dont les ressources biologiques sont très peu connues.

a. *Plage et dunes bordières: Espace convoité*

La plage de Zouara est celle qui, parmi les rares plages de la Tunisie, a plus ou moins conservé, jusqu'à présent, son cachet naturel et échappé à la construction des complexes touristiques à l'origine de la dégradation et de la régression des habitats naturels engendrant une raréfaction et une disparition de plusieurs espèces ainsi qu'une érosion génétique. L'accent est mis sur la diversité de l'arthropodofaune (voir dans ce manuel les sections 2.3.6–Diptera et 3.1-Coleoptera) qui constitue la composante principale de cet écosystème englobant la plage et le complexe de dunes bordières, ainsi que la diversité de la couverture végétale (section 2.3.5) de ce complexe.

Le haut de plage et les dunes meubles proches de la mer abritent un couvert végétal bien diversifié qui réunit une dizaine d'espèces psammo-halo-nitrophiles dont *Ammophila arenaria* (oyat) qui constitue la végétation pionnière de la fixation naturelle des dunes vives (Fig. 2.1.4). Les espèces animales rencontrées dans ce milieu sont représentées par des arthropodes, insectes et crustacés. Les crustacés isopodes *Tylos europaeus* et amphipodes comme *Talitrus saltator* et *Talorchestia brito* se rencontrent sous les débris mais le plus souvent s'enfouissent dans des terriers pendant la journée en dehors de leur période d'activité qui est plutôt nocturne. Ils se nourrissent de débris organiques divers et sont considérés de ce fait comme des dépolluants. Les insectes sont représentés par plusieurs espèces tels que *Phaleria acuminata* (Tenebrionidae), *Scarites laevigatus* et *Eurynebria complanata* (Carabidae).

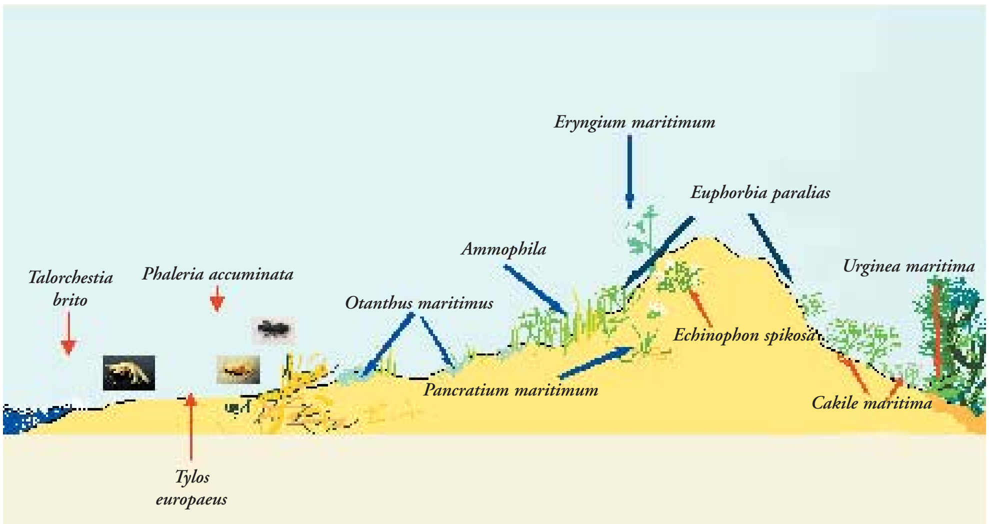

FIG. 2.1.4 *Diversité floristique et arthropodes communes de la plage et des dunes bordières de Zouara. Photos de gauche à droite:* Talitrus saltator, Eurynebria complanata, Scarites laevigatus

Nous insistons sur le fait que les *invertébrés ne font pas l'objet d'évaluation.* Pourtant, un bon nombre d'espèces sont des agents importants des processus écologiques.

Nous soutenons l'idée de la protection et de la fixation biologique des dunes par la plantation d'espèces locales telles que *Ammophila arenaria* faisant l'objet de collecte abusive par la population qui l'utilise pour des fins artisanales (Fig. 2.1.3 D).

b. *La forêt littorale naturelle unique en son genre*

La forêt de Zouara revêt une grande importance car c'est l'une des rares forêts côtières tunisiennes relativement peu perturbées et bien conservées. Cette forêt de chêne kermès (*Quercus coccifera*) est l'une des plus étendues en Tunisie. Comparée à la forêt plantée, la couverture végétale naturelle est bien plus diversifiée. On reconnaît *Juniperus oxycedra* et *J. phoenicea*, *Pistacia lentiscus*, *Phyllirea angustifolia*, *Retama monosperma*, *Asparagus acutifolius*, *Smilax aspersa*, *Potamogeton pectinatus*, *Viburnus tinus*, *Ruscus hypophyllum*, *Cynodon dactylon*, *Daphne gnidium*. A cette diversité floristique correspond une diversité faunistique qui a été analysée soit par un échantillonnage saisonnier de 3 milieux qui se distinguent par leur couverture végétale et par la densité de la végétation, soit par une recherche sous les pierres et la litière, soit encore par un relevé de certains signes de présence ou d'activité des animaux.

Parmi les vertébrés, les mammifères sont représentés par *Sus scrofa*, *Canis aureus*, *Vulpes vulpes*, *Genetta genetta*, par des rongeurs reconnus par la présence de nombreux terriers et les reptiles représentés par *Chalcides ocellatus*. Cette forêt abrite des espèces peu communes ou rares en Tunisie, tels le porc-épic.

Les invertébrés sont représentés essentiellement par des insectes, des myriapodes et des aranéides. Les crustacés récoltés sont des isopodes terrestres appartenant tous à la famille des Porcellionidae, *Acaeroplastes melanurus*, *Agabiformius lentus, Porcellionides sexfasciatus, Porcellionides pruinosus* et l'espèce endémique, *Porcellio variabilis*.

La forêt est exposée à divers agents dégradants tels que la déforestation et le feu. En effet, la disparition d'une partie de cette forêt côtière de chêne kermès aux environs de Tabarka, à cause des aménagements touristiques (hôtels, aéroport…), appelle à la nécessité de *conserver ce patrimoine* où des pieds de chêne kermès, remarquables pouvant atteindre jusqu'à 14 m de haut et 0,75 m de diamètre, lui confèrent un statut unique.

Par ailleurs, la disparition éventuelle de la couverture végétale induira un processus irréversible de désertification, par l'instabilité des dunes. En effet, la région est exposée à des vents violents qui auront pour effet le déplacement du sable dunaire vers le continent, à l'origine d'un *ensablement* et d'une *déstabilisation* du milieu; c'est le cas actuellement de certains secteurs de Zouara.

Suite à la disparition et la dégradation de la couverture végétale, on assiste à une diminution ou parfois même une perte de la diversité, particulièrement de la faune. Or, la diversité faunistique est encore très mal connue; il est donc très regrettable de voir cette *diversité s'éroder* avant qu'elle ne soit quantifiée pour pouvoir être gérée par la suite.

Nous soutenons l'idée de la création d'une *réserve naturelle* dans la forêt de Zouara, afin de conserver les groupements végétaux naturels qu'elle abrite, notamment les étendues de chêne kermès, ainsi que les stations qui comprennent des pieds de grande dimension de cette essence.

Cette réserve aura pour mission principale l'étude de *la biodiversité en vue de sa gestion, sa préservation et sa conservation*. Cette station de recherches doit être étudiée d'une manière très approfondie par des scientifiques de différentes spécialités afin d'éviter toutes les pratiques qui risquent de perturber le fonctionnement du site comme, par exemple, les introductions de nouvelles espèces.

Autour de cette réserve peuvent avoir lieu des aménagements qui permettent une *valorisation du site*. Ces aménagements ne doivent pas avoir pour effet une altération du milieu, surtout ses communautés biotiques. Ils peuvent consister en des pistes non carrossables, mais accessibles à pied, à vélo ou à dos de cheval. Ces pistes visiteront notamment les pieds de chêne kermès évoqués plus haut, ainsi que des endroits où une exposition pédagogique montrera aux visiteurs intéressés certaines des particularités du milieu et sa diversité.

c. *Le barrage et son entourage: zone humide pour les oiseaux d'eau*

Le barrage, récemment installé sur l'Oued Zouara, ainsi que son embouchure constituent une zone humide qui attire une avifaune très diversifiée. Ceci est dû particulièrement à la position géographique stratégique de ce secteur situé entre l'Europe et l'Afrique, d'une part et à son ouverture sur la Méditerranée occidentale, d'autre part. Au niveau de la région Nord-Ouest de la Tunisie, ce site est presque unique en son genre. A une échelle encore plus réduite, cette zone est formée par 3 stations structurellement différentes qui sont la côte sableuse (S1), le complexe d'étangs compris entre le barrage et la mer et sous l'influence des 2 types d'eaux, marine et douce (S2) et enfin le barrage (S3). Ceci a pour effet d'engendrer une diversité au niveau des ressources trophiques qui peuvent être soit d'origine marine, soit en provenance du barrage ou des dunes bordières.

A cette diversité des biotopes et des ressources trophiques correspond une diversité de l'avifaune. En effet, les observations mensuelles directes réalisées de septembre 2000 au mois d'avril 2001 ont permis d'identifier 19 espèces d'oiseaux répartis en 6 ordres et 9 familles. Parmi les espèces hivernantes, le Goéland leucophée *Larus cachinnans* est le plus abondant (49,6%), le Goéland d'Audouin *Larus audouinii* (8,5%), la Sterne caugek *Sterna sandvicensis* (6,03%), la Mouette rieuse *Larus ridibundus* (4,4%), le Grèbe huppé *Podiceps cristatus* (4,08%), le Gravelot à collier interrompu *Charadrius alexandrinus* (1,21%), le Grand cormoran *Phalacrocorax carbo* (0,9%) et l'Aigrette garzette *Egretta garzetta* (0,8%). Par son ouverture sur la Méditerranée, cette zone abrite des espèces de passage tels que le Fuligule milouin *Aythya ferina* (6,5%), la Foulque macroule *Fulica atra* (5,6%), le Grèbe à cou noir *Podiceps nigricollis* (4,08%), l'Huîtrier pie *Haematopus ostralegus* (0,9%), l'Héron cendré *Ardea cinerea* (0,5%) et le Canard chipeau *Anas strepera* (0,44%).

Dans le secteur (S1) formé par la mer, l'épandage alluvial situé à l'embouchure de l'oued et la plage sableuse à la base des dunes, 4 espèces sont présentes: le Goéland leucophée se nourrit et se repose dans le milieu marin; l'Huîtrier pie utilise l'épandage alluvial pour se reposer; le Bécasseau sanderling *Calidris alba* s'alimente au niveau de la ligne de rivage et le Gravelot à collier interrompu utilise la base des premières dunes pour se nourrir, pour se reposer et vraisemblablement pour nicher.

Certains oiseaux utilisent les petits étangs (secteur S2), situés entre la mer et le barrage, pour s'alimenter et pour assurer leur activité de confort. Il s'agit du Goéland leucophée, du Goéland d'audouin, du Grand cormoran, de la Mouette rieuse et de l'Huîtrier pie.

Enfin, le barrage (secteur S3), dont la diversité aviaire de 0,069 bits est la plus faible, abrite le Fuligule milouin et le Grèbe huppé qui utilisent ce milieu pour se nourrir et pour assurer leur activité de confort.

Malgré les conséquences du barrage sur le transit sédimentaire qui priverait la plage d'un apport de matériel sableux associé à la houle qui éroderait une bonne partie de l'avant côte de part et d'autre de l'embouchure, ce barrage et son voisinage constituent un site d'attraction d'une avifaune diversifiée qui mérite un *suivi* régulier par l'installation d'un *observatoire* ornithologique.

2.2 LE SITE DES KNEISS, TUNISIE: GÉOMORPHOLOGIE ET APTITUDES À L'AMÉNAGEMENT

Moncef Gueddari et Ameur Oueslati

Monotonie et faiblesses (des altitudes, des pentes et de la profondeur des eaux littorales); telles sont les caractéristiques qui se dégagent d'un premier contact avec la région. L'examen de près, du terrain, révèle cependant une variété indéniable de paysages et de modelés parfois d'une grande originalité ainsi qu'une richesse remarquable tant sur le plan environnemental que sur le plan patrimonial.

2.2.1 *Variété et originalité du paysage morphologique*

Du côté du continent: De la mer vers l'intérieur se succèdent, assez régulièrement, un domaine de plaines, un domaine de bas plateaux et un domaine de collines. L'évolution morphologique a légué une variété de formes et de modelés qui, malgré une certaine discrétion dans le paysage, sont d'une grande valeur scientifique et patrimoniale. D'une part, ils servent de repères pour l'histoire du terrain et la reconstitution des paléoenvironnements. D'autre part, ils recèlent les traces de différentes civilisations humaines allant des temps préhistoriques aux temps récents.

Les plaines ont une genèse très récente puisque constituées d'alluvions d'âge holocène à historique qui montrent le maximum de leur développement dans les sections des principaux cours d'eau et dans la marge littorale notamment autour de l'embouchure de Oued Ouadrane. Ici, l'accumulation prend une forme en éventail et s'étend sur une dizaine de kilomètres le long de l'oued en s'élargissant en direction du rivage. Les altitudes sont basses; au voisinage de la mer, elles descendent à 1 ou 2 m et parfois à quelques décimètres seulement et les pentes sont partout très faibles.

Les plateaux, situés entre 20 et 50 m d'altitude, sont généralement séparés des plaines par un talus de quelques mètres de commandement et caractérisés par des pentes également faibles à très faibles (<0,5%). Leur surface est le plus souvent régulière et continue. Mais elle peut être localement accidentée par de petites ruptures de pentes ou découpée par les eaux courantes ce qui l'a parfois réduite à des buttes allongées à sommet convexe ou plat: des "tables" situées à des altitudes différentes ponctuent le paysage naturel.

Les collines portent les points culminants de la région, le plus souvent comprises entre 150 à 200 m. Elles sont pourtant bien marquées dans le paysage grâce notamment à la variété de leurs formes et à la platitude de leurs sommets.

Collines et plateaux sont formés dans des matériaux sédimentaires récents néogènes à quaternaires. Les premiers montrent la plupart du temps un faciès argileux à argilo-sableux -gypseux de couleur rougeâtre à rose. Leur sommet est généralement coiffé par des croûtes calcaires ou gypseuses parfois épaisses et résistantes ce qui leur a souvent assuré une bonne protection contre l'érosion. C'est d'ailleurs grâce à ces croûtes que différents sommets ont pu conserver leur régularité.

Les formations quaternaires accompagnent surtout les principaux oueds où elles constituent l'ossature de terrasses étagées ou emboîtées marquant les étapes de l'évolution au cours Quaternaire. Certaines d'entre elles, à l'image de celles qui accompagnent Oued Ouadrane, renferment des vestiges archéologiques, historiques et préhistoriques, et ont de ce fait une valeur remarquable tant pour la recherche scientifique que pour le patrimoine.

Du côté de la mer: la topographie basse du continent passe insensiblement, dans la mer à un milieu original: les bancs des Kneiss qui correspondent à des hauts-fonds caractérisés par leur grande platitude, leur forme qui évoque une flèche littorale submergée et leur bathymétrie extrêmement faible. Les fonds sont très souvent à moins d'un mètre, voire à quelques décimètres avec des bancs étendus à fleur d'eau. Cette originalité est doublée par l'importance de la marée et l'existence d'un réseau hiérarchisé et complexe de chenaux sous-marins ou "oueds" (Oued Ed Dem, Oued El Baa, Oued Rjef Ben Sehil, Oued Boukhlef, …). Par marée basse des superficies impressionnantes sont exondées et la navigation devient impossible sauf dans les grands "oueds".

Sur le rivage, la morphologie est assez variée mais les terres humides et les falaises dominent tant par leur extension que par leur place dans le paysage. Les premiers, montrent généralement une zonation dans laquelle se succèdent de la mer vers l'intérieur marais maritimes à slikke et schorre caractéristiques, sebkhas (terres fortement salées et dépourvues de toute végétation) et chotts (auréoles de végétation halophile autour des sebkhas). Les falaises caractérisent la partie méridionale et sont taillées dans les argiles gypseuses mio-pliocènes.

Les marais maritimes montrent généralement deux parties bien individualisées. L'une régulièrement couverte et découverte, en fonction de la marée, c'est une slikke. L'autre correspond à un schorre caractéristique envahi par les eaux marines à chaque flot par l'intermédiaire d'un réseau, parfois très dense, de chenaux de marée.

Les schorres les plus étendues occupent: - le fond des baies et criques surtout celles qui correspondent à une embouchure d'un cours d'eau, - les sites abrités par un petit cap comme le cap de Skhira El Gdima, - les parties internes de grands chenaux de marée notamment les chenaux de Oued Maltine, Oued Grienech et Oued Rjef Ben Sehil. Leur surface est un peu partout occupée par une formation serrée d'halophytes dominée par des Salicornes.

Les falaises deviennent l'élément le plus apparent de la morphologie littorale à partir du port de Skhira El Gdima. Elles se détachent très bien dans le paysage grâce à leur commandement souvent compris entre 10 et 20 m et surtout grâce à leur teinte rosâtre qui reflète en fait la couleur la plus caractéristique des argiles gypseuses mio-pliocènes.

Outre les terres humides et les falaises, la région renferme quelques plages sableuses et estrans rocheux. Les premières se réduisent généralement à des liserés plus ou moins continus localisés surtout dans les petites criques ou à des accumulations provisoires au pied des falaises. Les seconds, sont rares du côté du continent mais prédominent dans les îlots les plus petits de l'archipel des Kneiss.

L'archipel correspond à une guirlande d'îlots qui émergent à peine des hauts-fonds: El Bessila, El Hjar, El Laboua (dit aussi îlot de Sidi Salah du nom du marabout qu'il renferme ou El Oustaniya c'est dire celui du milieu) et enfin El Gharbia.

El Bessila (l'îlot de la scille?), l'îlot le plus septentrional, le moins petit et le moins bas, a une forme grossièrement circulaire avec un diamètre maximal de l'ordre de 2,5 km. Les altitudes y sont le plus souvent inférieures à deux mètres sauf dans la partie septentrionale qui culmine à 7 m et où se situerait son premier noyau dont la constitution correspondrait, si on se réfère aux autres îlots, à un lambeau de grès marin eutyrrhénien. La plus grande partie est occupée par des sols salés de sebkhas ou de chotts sur des terrains meubles sablo-limoneux à sablo-argileux parfois remaniés par le vent. Les parties méridionale et occidentale, les moins exposées à la houle, sont occupées par un vaste schorre à surface découpée par une multitude de chenaux de marée.

El Hjar (l'îlot rocher, l'îlot du rocher ou l'îlot rocheux), El Laboua (l'îlot de la vase?) et El Gharbia (l'îlot de l'Ouest) sont beaucoup moins étendus. Le premier est le plus petit de tous avec à peine 10 m de diamètre et une hauteur de l'ordre du mètre. Sur le plan géologique, tous ces îlots ont une ossature de grès marin typique de la formation Rjiche maintenant bien connue sur les côtes tunisiennes et attribuée à l'Eutyrrhénien (environ 120 000 ans B.P.), épisode transgressif du dernier interglaciaire au cours duquel le niveau de la mer était supérieur à l'actuel d'une dizaine de mètres. Le rivage proprement dit est une microfalaise devancée par un platier rocheux à surface affectée par de nombreuses formes de corrosion et jonchée de débris de grès provenant de sa destruction ou arrachés à la microfalaise. On reconnaît aussi des fragments de roches allogènes et de céramiques issus des ruines antiques qu'on trouve dans les différents îlots.

2.2.2 *Une érosion marine menaçante et des rivages à haut risque avec une variation positive du niveau marin*

L'érosion marine et les signes de retrait du rivage qui en résultent sont reconnaissables dans le front de certains schorres, sebkhas et petites plages sableuses où ils sont généralement matérialisés par une microfalaise vive et/ou par des mottes de terres et des plantes déchaussées par les vagues. Les plus spectaculaires ou significatifs pour l'évolution récente caractérisent toutefois les falaises des environs de Skhira et les rivages des îlots de la partie méridionale de l'archipel des Kneiss.

Dans les falaises l'érosion marine agit par un mécanisme encoche-éboulement (Fig. 2.2.1). La fréquence des cicatrices au dessus des encoches et les nombreux éboulis dont certains atteignent quelques dizaines de m^3 de volume témoignent de l'importance d'une telle évolution menaçante pour différents aménagements et qui a sans doute été à l'origine d'un retrait important du trait de côte. On ne dispose pas de repères récents pour quantifier ce recul mais on peut voir qu'immédiatement au Sud de Borj Ennadhour il a déjà amputé un site archéologique antique d'une partie importante de sa substance.

L'archipel n'a plus le même visage que celui que lui connaissaient les romains: c'est en effet dans les îlots rocheux de l'archipel que l'appréciation du recul du trait de côte et de ses conséquences est la plus aisée. Car, aux indices morphologiques s'ajoutent des repères archéologiques et des données recueillies dans des textes historiques de différentes époques.

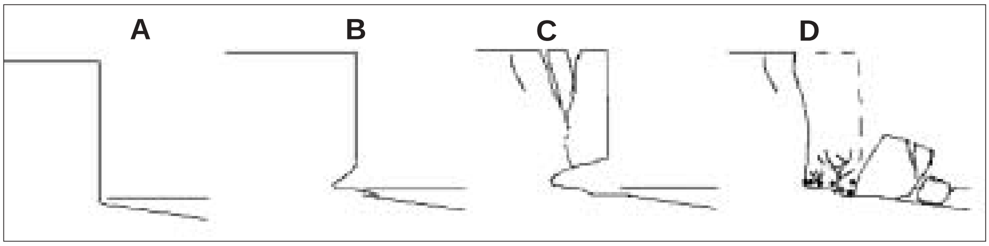

FIG. 2.2.1 *Mode de recul des falaises sous l'action des vagues: l'évolution commence par une encoche au pied de la falaise qui prépare à des éboulements. Les éboulis assurent une protection provisoire du pied de la falaise ce qui peut favoriser l'apparition d'une végétation adaptée. Le scénario reprend dès que ces éboulis sont démantelés par les vagues et leurs débris poussés par les courants*

Les eaux marines agissent à la fois par des processus mécaniques et biochimiques dont l'efficacité est matérialisée par une microfalaise à pied encombré de débris rocheux et par une multitude de formes de corrosion. L'importance du démantèlement est également attestée par des vestiges archéologiques antiques taillés par la falaise et dont les traces sont visibles même sur l'avant côte. Tout indique que l'archipel a connu une évolution importante et des modifications appréciables dans son extension et sa configuration au cours des temps récents. De fait, arguments de terrain et textuels indiquent que la tendance générale a été pour le tronçonnage et la réduction de la superficie des différents îlots, surtout ceux du Sud. Les îlots d'El Hjar, d'El Laboua et d'El Gharbia ont très vraisemblablement continué à être unis jusqu'à l'époque historique, probablement jusqu'aux tous derniers siècles pour El Laboua et El Gharbia.

Des investigations géoarchéologiques récentes (Trousset *et al.*, 1992) ont permis de confirmer l'idée selon laquelle les traces du monastère dans lequel s'était retiré Saint Fulgence (abandonnant sa dignité d'abbé vraisemblablement en l'an 503, 504 ou 505, pour se consacrer à la prière et aux travaux manuels) existent dans l'îlot d'El Laboua. Or, cet îlot est aujourd'hui très minuscule; il n'a que 45 m sur 44 m respectivement pour la longueur et la largeur et ne peut contenir une communauté de moines aussi importante que celle ayant accompagné le Saint homme. C'est qu'en réalité il a été, depuis, amputé d'une partie importante de sa substance.

D'un autre côté, en 1587, F. Lanfreducci et J.O. Bosio, dans leur *Costa e discorsi di Barbaria*, mentionnent les Friscioli qui sont les îles Kneiss, comme "deux petites îles avec des bancs". Il s'agit sans doute d'El Bessila d'une part et les trois autres îlots qui formaient une seule. La même idée se dégage chez d'Avezac (1948) qui avait remarqué que divers portulans catalans du Moyen Age et de la Renaissance ne cartographiaient sous le nom de Frixols que deux îles.

Une telle évolution, en particulier l'efficacité avec laquelle a opéré l'érosion marine, peut paraître énigmatique compte tenu du cadre naturel qui ne favorise pas une grande agitation des eaux marines. La hauteur des vagues est le plus souvent inférieure à 1 m et ne montre une certaine importance qu'à l'occasion de certaines tempêtes. Même dans ce dernier cas, elle n'excède presque jamais les 2 m. Les hauts-fonds sont à l'origine d'une séparation naturelle importante entre le large d'une part et la côte d'autre part. D'ailleurs, l'appellation arabe traditionnelle "SurKneiss" (le rempart des Kneiss) par laquelle sont désignés les bancs et les îlots qu'ils portent est fort expressive; car ces bancs constituent une espèce de digue, une barrière de protection contre la houle venue de l'Est mais qui devait aussi assurer à la côte une protection contre les envahisseurs depuis le large.

L'explication est à chercher surtout dans la tendance qui a marqué le comportement du niveau marin et la tectonique régionale au cours des temps récents. Si la mer a réussi à gagner autant d'espace c'est à cause de l'élévation historique du niveau marin maintenant attestée, sur les côtes tunisiennes, par de nombreux vestiges archéologiques submergés et dont la valeur se situe entre 20 et 40 cm. Dans la région des Kneiss ses effets ont été amplifiés par un affaissement sensible du sol côtier suite à une activité subsidente continue. Ceci est confirmé par exemple, par l'analyse des enregistrements marégraphiques du port de Sfax qui indiquent pour le vingtième siècle une variation positive du niveau marin de 5,7 mm/an (Pirazzoli, 1986), vitesse quatre à cinq fois plus rapide que la moyenne avec laquelle se fait l'augmentation du niveau de la mer à l'échelle planétaire.

C'est donc un terrain très sensible aux variations du niveau marin. Il doit être considéré comme à haut risque en cas d'une Elévation Accélérée du Niveau Marin (E.A.N.M.) comme celle que prévoient les scénarios de l'I.P.C.C. Une telle élévation entraînera accélération de l'érosion marine et extension des sebkhas en direction du continent, suite à l'intrusion des eaux marines et la progression de la salinisation aux dépens des plaines alluviales qui les bordent. Des îlots comme El Hjar ou même Laboua risquent de disparaître ainsi que le patrimoine archéologique qu'ils renferment.

2.2.3 *Une érosion hydrique dégradante dans le continent et à impacts multiples dans le domaine marin*

Souvent brutales, concentrées dans le temps et survenant après des périodes de sécheresse plus ou moins longues, les pluies donnent fréquemment lieu à des écoulements agressifs. Si bien qu'en dépit de sa faiblesse, le réseau hydrographique mène, une érosion parfois sévère et très menaçante surtout pour un patrimoine pédologique déjà limité et peu protégé, les sols étant souvent très minces à squelettiques et le couvert végétal ne dépasse presque jamais le stade d'une steppe dégradée.

Les effets de cette érosion, qui contribue à l'accentuation de la désertification déjà assez perceptible dans différents secteurs, sont particulièrement nets dans les argiles mio-pliocènes et les formations quaternaires qui ne bénéficient pas d'une protection par des croûtes, notamment dans le domaine des collines et à la faveur des ruptures de pente qui accidentent ici et là le domaine des plateaux ou qui caractérisent les berges des principaux cours d'eau. Le résultat est, en de nombreux endroits, un paysage très disséqué par un réseau très complexe de ravins; véritables "Chebkas" (terme très fréquent dans la toponymie locale et qui signifie terres très ravinées).

La contrepartie de cette érosion sont des alluvionnements parfois impressionnants dans la partie aval des plaines littorales et dans le domaine marin où ils ont des conséquences multiples. Pour le rivage ils sont plutôt bénéfiques puisqu'ils lui procurent une partie de son corps sédimentaire. Mais au cours des événements pluviométriques majeurs les apports des oueds, surtout les plus grands comme Oued Ouadrane, sont à l'origine d'inondations catastrophiques et peuvent s'avancer loin vers le large notamment lorsque le paroxysme des crues coïncide avec une marée descendante ou lorsque les hauts-fonds sont exondés. Cette avancée, aidée par les oueds sous-marins du fait de la localisation de leurs principales branches dans le prolongement des oueds continentaux, peut alors, compte tenu de l'importance des hauts-fonds, influencer l'environnement marin au moins sur le plan sédimentologique. C'est ce qui se serait produit à l'occasion des inondations de janvier 1990 et surtout celles de septembre-octobre 1969. Tous les pêcheurs, d'un certain âge, s'accordent sur le fait que "la mer des Kneiss a subi des changements importants suite aux crues de 1969". Ils précisent que "certains secteurs sont devenus moins profonds et que les secteurs proches du rivages sont devenus plus vaseux".

Tout fait comme si ces hauts-fonds font partie à la fois de la mer et du continent; c'est l'autre face de l'originalité de la région des Kneiss.

2.2.4 *De l'intérêt des géosystèmes en cours de formation au pied des falaises*

Les falaises de Skhira sont, en différents endroits, soumises à une double attaque: l'érosion marine à la base et l'érosion hydrique dans leur partie supérieure. Celle-ci a réussi à créer un réseau de ravins parfois très dense et profondément encaissé. Le phénomène est initié par de petites cicatrices qui évoluent à la fois par érosion linéaire, latérale et surtout régressive. C'est une évolution relativement rapide ainsi que le laisse croire par exemple, le déplacement répété des pistes qui passent à proximité des têtes de ravins.

La contrepartie de ce démantèlement est une progradation parfois remarquable de l'estran. Si bien qu'en plusieurs endroits le rivage a été repoussé au point de mettre les falaises à l'abri des vagues parfois de façon permanente. En fait, plusieurs situations existent allant de l'apparition de la petite plage, accompagnée ou non de dunes, à la plaine alluviale de largeur plurihectométrique; elles illustrent les différentes étapes d'une évolution dont la connaissance peut être très instructive sur le plan morphosédimentaire mais aussi pour la dynamique de l'environnement côtier dans son ensemble (Fig. 2.2.2). Car au fur et à mesure que ces espaces gagnés sur la mer évoluent des formes de vie, végétale et animale, font leur apparition.

2.2.5 *Les constructions éoliennes sur les berges des sebkhas: des géosystèmes en danger*

Par sa localisation littorale et son climat semi aride, la région des Kneiss est très favorable à l'activité éolienne. Celle-ci est déjà, par la déflation exercée à la surface des plateaux, à l'origine de différentes formes de désertification et de vastes regs (Hmada). Les formes de construction se rencontrent au bord de la mer à la faveur des

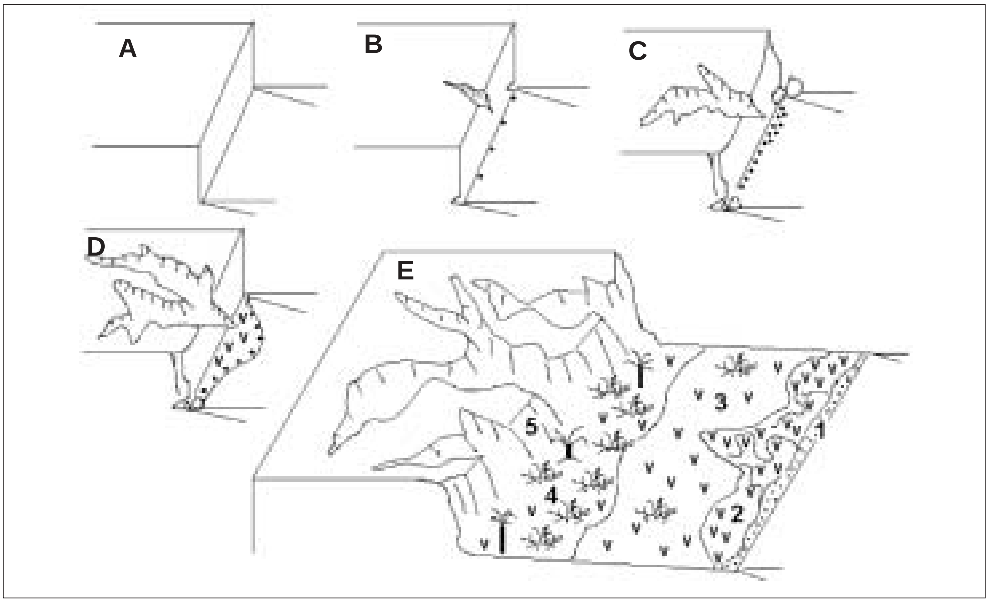

FIG. 2.2.2 *Différentes étapes de la mise en place des marais de pied de falaise: le scénario commence par l'apparition d'une petite plage pour évoluer vers un espace parfois large de plusieurs hectomètres. Au fur et à mesure, s'installe une végétation et une faune adaptées. L'évolution a par endroits conduit à une zonation qui montre de la mer vers l'intérieur: une plage sableuse* (1)*, un schorre* (2)*, une sebkha ou un chott ponctués par de petites dunes* (3)*, une zone à nebkas bissonnantes* (4) *avec parfois quelques palmiers, une falaise morte découpée et ravinée par les eaux courantes* (5)

quelques plages sableuses et autour des zones d'épandage des oueds. Mais les plus étendues caractérisent les marges des sebkhas.

De fait, le piégeage, par la végétation des chotts, de la matière arrachée par la déflation qui agit à la surface des sebkhas, lorsqu'elles sont à sec, a souvent favorisé la formation de dunes isolées ou regroupées en champs plus ou moins étendus mais particulièrement marqués dans le paysage ce qui leur a souvent valu des appellations significatives, dans la toponymie: "Erg" pour les champs relativement étendus et "Gataya" pour les dunes isolées au milieu des sebkhas parce qu'elles s'apparentent à des îlots lorsque ces sebkhas sont inondées ou lorsque s'installe le mirage en été.

Mais outre leur importance paysagère ces espaces ont un intérêt de biodiversité. D'une part, les dunes portent un cortège floristique important, qui est décrite dans la section 2.3.5. D'autre part, une faune variée y trouve refuge. On ne peut par exemple, ne pas noter la remarquable densité des trous d'animaux fouisseurs creusés dans les "gatayas" et les autres dunes évoluant encore à l'état naturel.

C'est cependant un écosystème menacé et qui risque d'être compromis suite à l'extension des cultures. Une partie non négligeable des espaces dunaires de bordure de sebkha a en effet été aménagée en vergers et annexée aux propriétés agricoles. Cette pratique, commencée depuis plusieurs années si l'on juge par l'âge des plantations, est toujours en cours. Elle se fait parfois à un rythme rapide car ne nécessitant ni gros efforts ni gros moyens, les dunes étant faites d'un matériel meuble et leur végétation facile à éradiquer.

2.2.6 *Quelles recommandations pour l'aménagement?*

Si le littoral des Kneiss est restée jusqu'à très récemment à l'abri des aménagements c'est parce que son environnement naturel est jugé peu attractif notamment à cause de la grande extension des terres humides et des estrans vaseux ainsi que des contraintes que pose la faible profondeur de ses eaux à la navigation. Ceci, s'il n'a pas favorisé la région sur le plan économique, a constitué une chance pour le milieu naturel qui a échappé à bien de problèmes dont souffrent d'autres milieux littoraux fortement anthropisés comme les plages.

L'implantation à Skhira d'une activité industrielle polluante, notamment l'usine de phosphates (S.I.A.P.E.), a certes des incidences au niveau du développement local; mais elle témoigne d'une continuité de la marginalisation du milieu naturel ou en tout cas de l'existence d'insuffisances dans la définition de ses aptitudes réelles à l'aménagement.

Les investigations géologiques et géomorphologiques ont montré que la région, à la différence de l'impression que peut avoir un visiteur pressé, recèle des potentialités multiples parfois de très haute valeur environnementale et patrimoniale très insuffisamment valorisées. De plus, sa nature en fait un milieu à originalités multiples et unique en son genre en Tunisie et même dans l'ensemble du bassin méditerranéen. Mais c'est en même temps un milieu très délicat et hypersensible aux interventions de l'homme ainsi qu'aux variations d'ordre naturel; différents compartiments appellent déjà des interventions de protection. L'une des voies qui nous paraît, en somme, s'adapter le mieux à lui c'est d'en faire un parc naturel et un espace de découverte de la nature par la recherche scientifique et par un tourisme culturel.

Parmi les données que toute intervention, visant la valorisation de la région, son développement ou l'élaboration de plans d'aménagement doit considérer on insiste en particulier sur:
– la valeur paysagère et l'originalité du site;
– le patrimoine géologique et archéologique important: préserver et valoriser les coupes géologiques et les formations marines ou continentales significatives pour l'histoire de la région ainsi que les vestiges archéologiques préhistoriques et historiques;
– la remarquable faiblesse de la bathymétrie qui rend le milieu marin particulièrement sensible aux apports d'origine continentale aussi bien naturels qu'anthropiques: apports des eaux courantes, apports de substances polluantes;
– la grande fragilité des constructions éoliennes, surtout en bordure des sebkhas, et leur intérêt de biodiversité à travers les formes de vie qui leur sont associées ou qu'elles abritent;
– l'instabilité des unités naturelles et les mutations qu'elles ont connu récemment ou qu'elles sont entrain de vivre: les uns disparus, menacées de disparition ou modifiées

(îlots méridionaux des Kneiss), les autres en cours de formation (au pied des falaises par exemple) et offrent une occasion remarquable pour assister à la genèse de certains écosystèmes permettant de mieux connaître leur nature et leur exigences;
- les tendances évolutives dans lesquelles s'inscrit la dynamique qui caractérise de telles unités naturelles: tenir compte en particulier de la variation positive du niveau marin, de la subsidence active du sol côtier, du retrait du trait de côte et de l'incision du réseau hydrographique;
- les risques naturels divers, surtout ceux dont les effets peuvent être facilement accentués par des interventions humaines imprévoyantes: érosion marine (par exemple, suite aux constructions très proches du rivage ou à proximité du sommet des falaises), désertification (suite à un défonçage des croûtes ou à une destruction de ce qui reste du couvert végétal), inondations (suite à une multiplication des aménagements dans ou à proximité des lits des oueds et des zones d'épandage), une grande sensibilité aux variations du niveau marin (accélération de l'érosion marine, progression de la salinisation en direction des terres basses littorales, ...).

2.2.7 *Références*

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2.3 CASE-STUDY: ZOUARA AND ÎLES KNEISS, TUNISIA

Louis F. Cassar, Edwin Lanfranco, Josienne Vassallo, Paul Gatt and Ewan W. Anderson

2.3.1 *Background*

Chott el-Zouara lies on the coastal plain east of Tabarka, on the northwestern Tunisian littoral. Its watershed extends a considerable distance inland, in the general direction of Beja, to and beyond the surrounding mountain range that includes Jbel Abiod, Jbel Msid, Jbel Kreroufa and Jbel Sidi Mhammed. The study-site proper forms part of a series of beaches and embayments, which occurs between Tabarka and Cap Negro, aligned in a northwest-facing direction (Fig. 2.3.1).

Infrastructural development in the Chott el-Zouara region, including the construction of a dam relatively close to the coast, aimed to harvest water run-off upstream of the Zouara dune-field, has led to significant changes in the hydrological regime and, anon, in the sediment dynamics of the coastal area occurred. Over the years, particularly throughout the duration of the MECO project (1998-2001), an overtly apparent transformation was registered along the beach and foredune zone at Zouara beach, as a result of a marked decreased in sediment fluxes.

Fig. 2.3.1 *Zouara on the northwestern Tunisian littoral*

Fig. 2.3.2 *The Kneiss archipelago in the Gulf of Gabes*

Kneiss Islands (Îles de Kneiss) and adjacent coastline constitute a lowland area with inconspicuous features (Fig. 2.3.2). The islet group lies in the Gulf of Gabes, off the coast of El Khouala, between the coastal towns of Mahares and Skhira. Apart from providing relatively good fishing grounds for locals, the islets are important from the point of view of avifauna. So much so, a stringent vigilance is maintained by local authorities and all visits to the islets, even for scientific purposes, are rigorously monitored. The islets and mudflats are an important staging point for various species of seabirds, waders and waterfowl. The islets' potential for environmental education is immense, but this needs to be balanced out with the need to safeguard the area for both its socio-economic and ecological qualities.

2.3.2 *Site characterization*

Zouara: The immediate coastal sector of Zouara-Nefza comprises a beach zone and accompanying dune field, in parallel to the shoreline with dune ridges generally trending northeast to southwest (at the time of survey); the entire area is set in a large natural embayment (Fig. 2.3.3A). At the waterfront, the length of the beach is approximately 15 kilometers. The coastal dunes stretch back from the foredune/back-beach deposit zone quite some distance inland, where these eventually converge onto an area of higher consolidated dune deposits. It is assumed that aeolian depositional processes influenced the landscape for a number of kilometers inland in the past, certainly before any human intervention to stabilize the region with woodland, but possibly also during a different climatic regime. Evidence of past aeolian development can be seen as far inland as twelve kilometers or so. Although the vegetation on the consolidated dunal area between Zouara beach and the main Nefza thoroughfare was mapped, some of which formed part of a former afforestation programme to stabilize the sand, it must be noted that there was no opportunity to examine the topography of the said area in great detail. An extensive *oued* system, now dammed, discharges into the sea towards the northeastern end of the beach while at the southwestern end there is one small *oued*, which acts as a seasonal discharge channel. Clearly, a thorough investigation on the influence, if any, of this *oued* on the beach zone and dunes at Zouara will need to be conducted.

The wind-rose for Tabarka shows that the dominant waves approach from the sector between west and north-northwest. In terms of force, the strongest are from the northwest and north-northwest and therefore approach almost frontally to the coastline. The prevalent winds are from the north-northeast and southwest. Since the system is largely sheltered from southwesterly winds, it is likely to be the north-northeast winds which are of most relevance. From aerial photographs, it appears that alongshore drift, the movement of sediment in nearshore waters, is from southwest to northeast; however, further investigation may well be required. There are a number of re-curved features at or just below the waterline, which illustrate this point. However, given the pattern of shallows offshore, it does appear that there may be, at certain times of the year, a number of minor circulation cells. The effect of the north-northeast winds is seen in the drifting of the sand on the beach. Both ripples and sand shadows show clearly the significance of the pre-

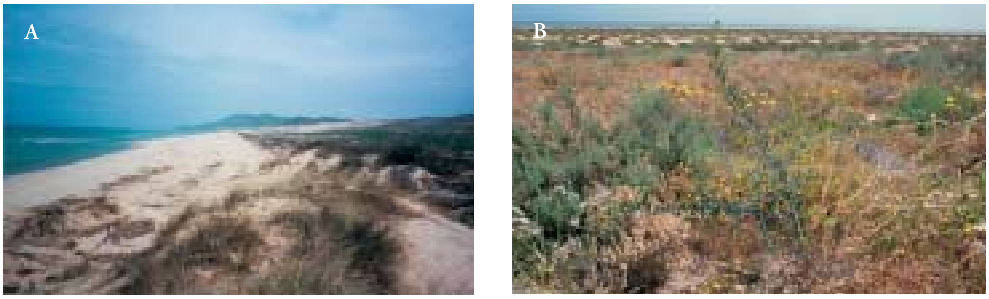

Fig. 2.3.3 *A general view of Zouara (A) and Kneiss (Bessila Islet) (B)*

dominant wind, with sand contours trending, generally, NW-SE; hence, with a SSW lee-side.

Bessila Islet, together a number of adjacent banks, mudflats and other islets, some bearing a halophytic vegetation, is situated on a submerged spit which is characterized by a pattern of former *oued* channels (Fig. 2.3.3B). Bessila is the largest entity within the Kneiss group. The neighbouring coastline includes *sebkhas* and, possibly, relict aeolian mounds. The wind-rose for Sfax, located to the north of Bessila Islet, shows that the prevalent and dominant winds are primarily from the east, followed by the north-northeast and north. This would indicate a movement of material along the coast from the northeast towards the southwest. The spit on which Bessila Islet stands provides evidence of this direction. The wind-rose for Gabes, to the south of Bessila Islet, is slightly different but again confirms the dominance and prevalence of winds from the east. In the case of Gabes, the next most important winds in terms of both dominance and prevalence are from the east-northeast followed by the northeast. Since, in this area, the coastline tends to trend from southeast to northwest, the movement of material would be northwards. Thus, the Gulf of Gabes has within it counter circulating systems. This may account for the very sharply recurved nature of the distal end of the spit on which Bessila Islet is located. Notwithstanding the foregoing observations, long-term research in the area may be required in order to verify assumptions made. Moreover, the Gulf of Gabes region is influenced by tidal fluctuations, which have a bearing on a wide range of processes including complex nearshore sediment dynamics and coastal currents.

General discussion: Both coastlines trend from northeast to southwest; while that at Zouara-Nefza is predominantly upland (although nevertheless coastal), that in the area of Kneiss Islands is clearly lowland. Both appear to have had a complex history of sea level change. In the case of Zouara-Nefza, it is postulated that at a higher sea level, the present dunal area was indeed a bay. As the sea level fell, material was brought by both the *oueds* and alongshore from the southwest. Significant sedimentation and aeolian effects is thought to have contributed to the development of dunal fields in the region. It would seem plausible that at a time when sea level fell considerably below its present level, dunal development would have extended to what is today an offshore zone.

Whether the new cycle of submergence is still active today can only be assessed from more detailed fieldwork and monitoring. It would appear that the foreshore is a particularly dynamic area.

In the area of Kneiss Islands, from an initial appraisal, it would appear that much the same sequence of eustatic change could be discerned. As is the case with most mudflats, the Kneiss system made up of islands, saltmarshes and sebkhas is far from featureless. It exhibits a complexity of tidal channel networks (presently both on land and in the water), 'sediment mound' topographies and 'slope terraces'. It is surmised that the detailed *oued* channel pattern could only have been produced sub-aerially. In contrast to the Zouara-Nefza beach sector, the terrestrial sector of this area appears geomorphologically more static. The apparent seaward colonization by vegetation also indicates that there is some kind of stability, at least on those areas, which do not experience too-frequent immersion. On the other hand, the surrounding areas of the lower intertidal zone are, almost certainly, geomorphologically dynamic, with sediments being transferred during tidal cycles (emersion/submersion cycle). At such time, a considerable recycling of sediments occurs, depending on material erodibility, the processes of which are vital for the maintenance of mudflats. Apart from sediment transfer during tidal cycles, the region is almost certainly influenced by sea currents. Evidence of this is the occurrence of large beached pumice rocks (size: 250 mm) on Bessila; considering that the nearest volcano-generated rock materials occur a considerable distance from the Kneiss islet group, it is clear that sea currents also play an important role in the transport of sediments and other materials[1].

2.3.3 *Field survey methods*

Assessment of landscape features: For both sites, if geomorphological systems and topographic alteration are to be identified and change anticipated, it was considered critical to obtain measurements of current landforms and an assessment of the causes leading to degradation, particularly, of vegetation and, more specifically of the Zouara dunes. In each case, therefore, detailed profiles were made and field measurements taken. When accurate larger scale maps are available, some of these profiles will allow identification of the main landscape features such as storm wave swash bars. Changes in landscape features can then be monitored by re-profiling.

In the case of geomorphological transects, for each profile, the orientation was recorded using a prismatic compass. A note of the position of the transect line was made, either in relation to other features or to previous transects. A detailed examination of the transect line was made and the limits of each major facet were marked. A facet is normally taken to be a straight rather than a curved slope element. In coastal environments, with the possible exception of dune slopes, facets are far more common than curved elements. Furthermore, angular measurements cannot be made of curved elements and therefore curves were divided into straight facets. For each

[1] The pumice may also have originated from roman ruins in the area.

facet, its angle from the horizontal was measured using an Abney Level. Length measurements were made either using the 15 m linen tape or by standard paces. Apart from these basic characteristics, potentially significant factors such as (i) vegetation types, (ii) sediment compaction, and (iii) the occurrence of debris along these transects were noted. Field investigations on the status of the vegetation/habitat-types and the dunal systems (in the latter case, Zouara) were conducted by way of standard searches, belt transects and direct measurement using prismatic compass, clinometer and measuring tape. In particular, the foredune zone at Zouara beach was investigated thoroughly in terms of its vegetation and dune morphology and coherence. The entire foredune sector was measured (physical dimensions; angles of slope; dune hollows) and its physical relationship with other components of the beach/dune field assessed. At Kneiss and el Khaouala, where the topography is generally quite flat, the survey focused mainly, but not exclusively, on vegetation patterns of the mainland (el Khaouala) and Kneiss islet.

Profile plotting and field observations: Using transect data, a series of profiles was plotted for each a scale of 1:500. This allowed an accuracy of 0.25 m for distance measurements. Angular records were plotted to the nearest 30' of arc and, as is standard practice for such profiles, the vertical measurement was trebled. Without such exaggeration, it would be difficult to detect any features given the preponderance of low angle facets. Since the measurements were made in facets, no attempt has been made to smooth the plotted curves. It is felt that when the procedure needs to be replicated for monitoring purposes, the dimensions of each facet need to be clearly identifiable. Thus, the profiles appeared somewhat angular.

For the beach sector of Zouara, transects were measured to identify beach form in what appear to be the three major sectors of the beach. From the entry point of the road, taken to be a fixed point, to the northwest is a sharply defined sand mound not unlike a dune crest, which, apart from the break for the *oued* entry, backs the beach. Evidence from aerial photographs together with the extraordinary rectilinear nature of this sand mound indicates that, if not entirely manmade, it is to a large extent artificial. To the southwest of the road entry point, the dunes have a far more natural appearance and are less rectilinear.

From the road entry point to the river, a swale immediately inland of the sand mound has obviously been cleared by earth moving equipment, presumably to reinforce the sand mound. Immediately beyond the breach made by the *oued*, the area has led to a ponding of water, the volume and character of which appeared to change fairly significantly from year to year. Further to the northeast the pattern of dunes inland looks natural and relatively undisturbed. In this section there is a clear difference in height of the dune, which backs the beach. Lower dunes are succeeded to the northeast by higher dune crests, constituting a dunal succession; this may be due to the larger dunes being located downwind of prevailing northwesterly winds.

The onset of the highest dunes coincides with:

I. the widest extent of the beach;
II. a shoreline promontory;

III. the northeastern termination of ponding as water erosion on the landward side of the dune; and
IV. the commencement of foredune and back-beach development.

The interpretation of this assemblage clearly requires more detailed fieldwork. Throughout the length of dune measured, the use of brushwood reinforcement was in evidence (refer to threats and impacts below).

Transects were taken in three sections:
I. northeast of the oued ;
II. between the oued and road entry point; and
III. southwest of the road entry point.

Each transect was measured at a constant orientation of 325°, approximately normal to the waterline. The distance between each transect was measured by standard pace. The resulting profiles have been plotted, in order, from the northeast to the southwest. Each begins at the waterline (left-hand end) and ends at the back of the beach, normally, at the top of the foredune (first dune ridge). For detailed analysis, it will be necessary to have an accurate large-scale map on which the lines of the transects could be plotted. Using the profiles alone, it was noted that the width of the beach varies very considerably, in general narrowing from the northeast towards the southwest. However, it was clear from the length of the profiles that there are also embayments.

Immediately above the waterline, a wide variation in facet angle from a steep cliff-like feature to a very gentle slope was recorded. Towards the backshore (at the point where back-beach deposits form), there was a greater consistency of profile. Foredune and foredune relicts occurred in some areas. The angle of the dune face appears relatively constant although, this is to a degree a matter of judgment as the slope is generally convex in shape. The main conclusions are that the beach varies considerably in width, possibly as a result of sediment fluctuations, and that the foreshore appears volatile while the backshore seems relatively stable, although possibly experiencing incompatibility where beach-dune sediment budget is concerned. When the profiles can be plotted on a map, it will be possible to identify the length of beach berms and other features, which at present can only be intimated on the profiles.

In the coastal area adjacent to Kneiss Islets, two topographical transects were made. As with the Zouara-Nefza transects, distance was measured using the 15 m linen tape. For both transects, the distances involved were relatively great and, to aid the identification of features, the limit of each facet is numbered in the plotted profiles. Concurrently, belt transects were made on both the mainland at el Khaouala and on Bessila.

Profiling at Bessila revealed a broad *sebkha*-like formation (salt-marsh area) which follows a narrow beach covered with organic material and flotsam that extends effectively across a considerable length of shoreline. There are then what can be interpreted as narrow sand mounds not unlike raised beaches fronting dune-like assemblages (? relict dunes), the crests of which extend inland from the low-lying shore.

The profile extends from sea level to inland mudflats, which are also taken to be at sea level and shows a fairly substantial overall rise and fall in the topography.

A detailed topographic transect was made across the higher locations of Bessila which otherwise comprises mudflats little above sea level. The only eminence not examined, consisted of a narrow sand mound line in the southwest of the islet. The profile reveals the general flatness of the landscape onto which are superimposed minor undulations. Given the material of which they were made, it is reasonable to suppose that these are, in-part, relict aeolian mounds. From sea level, the profile rises to a low plateau then descends to a flat relatively extensive plain. From the plain it rises to a relict sediment mound, the crestline of which is shown by a major sediment mound, exhibiting a flattened crest. The length of each ridge was measured by standard pace. The low plateau extended for 364 m and the major sediment mound for 996 m.

2.3.4 *Observations on sand dunes and surrounding habitats at Zouara*

The coastal area at Zouara consists of a wide embayment, not unlike a linear beach setting. The study-area constitutes a beach zone, a dune field, a *oued* system developing into a perennial watercourse (since the river is now dammed), and a hinterland, which extends some twelve kilometres inland towards the Zouara-Nefza thoroughfare.

It is widely acknowledged that an active dune field is highly dependent on the interaction between a number of key elements required for coastal dune development. Typically, an active dune field would consist of a **sediment bank** located in an offshore or foreshore zone; the wet/dry transitional beach boundary, and an active foredune area, known as the **transit zone**; and, a **resting zone**, which comprises the stable dune area. For these entities to occur, an ample supply of sediment is required together with the principal agents or geomorphological processes involving aeolian sand transport and deposition, and, a characteristic vegetation.

Sediment supply occurs as a result of alongshore drift from eroding headlands, cliffs and other coastal formations (including other beach zones and dune systems), as well as by fluvial sources such as rivers and valleys, and directly via the seabed. In locations experiencing a positive alongshore sediment budget, coastal foredune assemblages would tend to develop in a sequence that is related to the gradient of alongshore sediment supply.

In the case of Zouara, it is largely assumed that the prevailing situation *vis-à-vis* the foredunes, is due to the interruption of sediment, both in a spatial and temporal context, as a consequence of the new dam construction. Long-term erosion of the foredune assemblage in any dune system often leads to the initial enlargement of the dune proper. However, prolongment of this phenomenon due to alterations in sediment fluxes (as a result of fluctuation in fluvial discharge at the coast) may subsequently lead to deflation of the main dune ridge structure.

Before the dam was constructed, the Zouara coastal sand dune system may have been described as a *fluvial delta sediment system,* whereby the source of sediment was, indeed, the system of *oueds* that eventually culminated in the river downstream, which flowed out into the sea at Zouara beach. In the Zouara case, the spatial association began adjacent to the sediment source (river mouth) where a highly positive beach budget and low dune budget occurred. Alongshore drift gradient would have shown a decreasing beach budget accompanied by an increasing dune budget. This morphological sequence of events would lead to a very low foredune at the point adjacent to the fluvial source and increasing in dimension in the alongshore direction due to an enhanced dune budget. This was indeed the case at Zouara. However, with the relatively recent damming of the fluvial source and consequent decrease in sediment supply, the foredune zone experienced a sustained loss of its accumulated mass.

During the first year of research at Zouara it was predicted that should erosion continue at a steady pace, and, as a result of which, the beach budget deficit grows, it is likely that the foredune would continue to lose mass. Under a prolonged negative budget, it was felt at the time that the foredune would eventually decrease in size and subsequently undergo morphological changes such as deflation of the ridge structure. It was further envisaged that in the long-term the dune might experience a sequence of attenuation stages that will lead to a 'permanent' loss of foredune structure coherence. If this predicament for Zouara was correct, then the dunal system, at least, that adjacent to the river mouth, was considered to be exceedingly vulnerable. Such interpretation was based on the fact that some of the foredunes appeared to have become quite flat-ridged due to an evident loss in aeolian dynamism and, as a result, a number of blow-out formations (excessive wind erosion and lack of sand material input) and gullies had formed on and around the foredunes' area.

In a relatively short time-span the Zouara foredunes became less stable and it soon became evident that dunal vegetation would find it harder to establish itself with success. Throughout the study period (1999-2001), degradation was observed to rapidly set in. This was largely due to a number of factors, namely the significant decrease in sediment supply coupled by a lack of adequate vegetation cover to effectively stabilise the dune face and to act as an interception medium for descending saltating sand grains; higher rates of sand transport and low deposition levels often result from the latter. The presence of dune vegetation increases the amount of humus and other detrital material resulting in better soil conditions and water retention capabilities. In the case of the Zouara dunes, the situation is likely to worsen since a considerable section of the foredune has already began to lose much of its vegetation cover.

Having established a baseline on a number of components, which make up the Zouara system, monitoring was identified as the only short-term option prior to proposing any intervention plans. In this respect, on-going observations were conducted, over the three years of the project's duration, on the dune system, the beach and the river mouth zone. The beach was monitored in terms of depositional sand budgets on its surface; where the material was likely to be moving and subsequently deposited; and, whether the trends of beach-line erosion are continuing in the future, at the present rate. In the long-term, it would be important to establish whether there is any evident retreat of the present shoreline and any significant build-out of sand

FIG. 2.3.4 **(A-F)** *Degradation of dunes observed at Zouara throughout the study period (1999-2001).* **(A)** *Evidence of beach-face erosion (1999).* **(B)** *Detail (1999).* **(C)** *Significant sediment loss over a span of ten months (2000).* **(D)** *Permanent structures as baseline for measuring erosion (2000).* **(E, F)** *Accelerated erosion as a result of the disruption of aeolian processes; note scraping of the beach surface* **(E)** *and collapse of permanent structures* **(F)** *(2001)*

FIG. 2.3.5 (**A**) *Fluvial discharge: the river mouth at the coast (1999).* (**B**) *Estuarine formation at the former river mouth (2000).* (**C**) *The same river mouth now changed into a lagoon-type environment (2001)*

bars offshore. Furthermore, the foredune zone was monitored in terms of vegetation coverage, morphology and coherence. In no uncertain terms, the beach (both shoreline and surface) eroded severely at a fantastic rate, as a result of which the foredune was also negatively influenced due to a prolonged negative beach/dune sediment budget and experienced deflation of its general structure (Fig. 2.3.4). In the case of the river mouth zone, considerable change was also noted to have occurred. From an initial dune/marsh habitat, the area was fast transformed, first into an estuarine then a lagoon-type environment (Fig. 2.3.5). No doubt, these dramatic topographic and habitat changes (Fig. 2.3.6), which occurred in the short-term, will have had a negative impact on the biota of the area, and shall continue doing so until the rapid rate of induced change ceases and the landscape becomes stable once again.

2.3.5 *Vegetation*

Zouara (Fig. 2.3.7)

The Zouara dune includes most of the typical Mediterranean dune species, however the pre-dune assemblage is highly impoverished. Some dune species, which are generally common in most Mediterranean dunes, are rare, as in the case of *Cakile maritima* and *Elytrigia juncea.* The dominant species on the dune crest is *Ammophila littoralis,* others being *Eryngium maritimum* and *Euphorbia paralias.* The dominant annual was

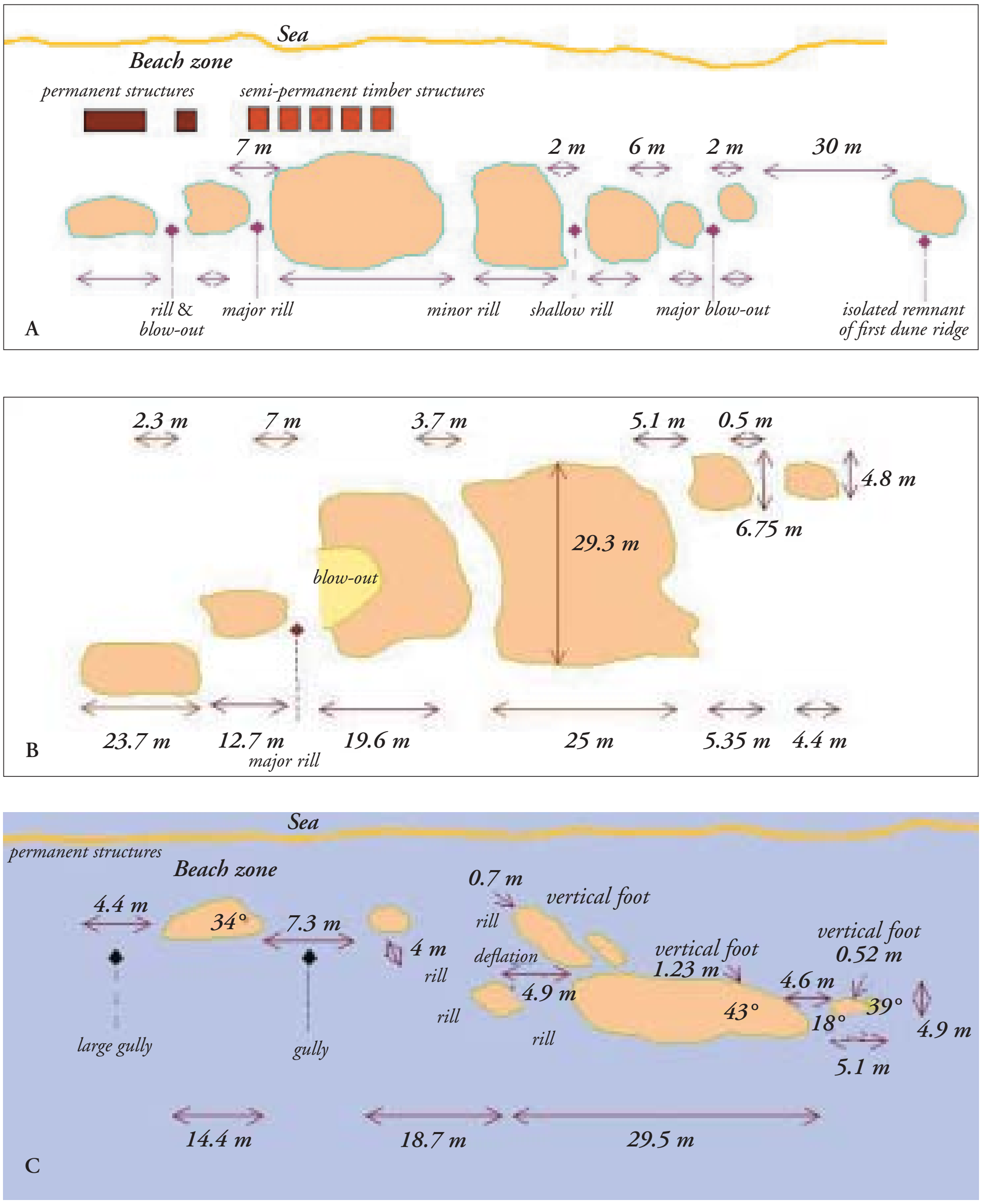

FIG. 2.3.6 Zouara: (A) *Foredune as at 1999.* (B) *Foredune as at 2000.* (C) *Foredune as at 2001*

Cutandia divaricata while secondary dominants were *Silene succulenta* and *Polygonum maritimum.* The fixed dune has been stabilized by plantations of *Acacia saligna* and *Acacia retinoides.* The dune crest has been topped by a mass of brushwood, possibly to prevent the sand from creeping onto the wooded area. Originally there must have been a large population of *Retama raetam*, remnants of which still exist within the *Acacia* planting as well as in the estuarine area (see below) and the Pinewood undergrowth.

Where the watercourse opens into the sea, an estuarine habitat has been created with mixed vegetation including both dune species and some marsh species. Thus, there is the characteristic Mediterranean watercourse community with *Nerium oleander, Tamarix* sp. and *Vitex agnus-castus* as well as typical marsh species such as *Juncus rigidus* and *Holoschoenus vulgaris.* The area further inland from the dune has been wooded with pines, particularly Stone Pine (*Pinus pinea*), and Maritime Pine (*Pinus pinaster*). Prior to being wooded this must have originally been a typical maquis formation of fixed dunes as evidenced by the persistence of typical species of this formation such as *Juniperus macrocarpa.* The undergrowth includes both dune species and maquis species. Thus most species occurring in the dune proper are also found here, together with other dune species such as *Cyperus mucronatus.* Maquis species includes some *Cistus* spp., *Halimum halimifolium, Quercus coccifera, Quercus ilex* and *Olea europaea.*

List:	*Acacia saligna*	p	*Acacia retinoides*	p D
	Ammophila littoralis	d D	*? Anthemis* sp.	m
	Cakile maritima	d R	*Casuarina* sp.	p
	Centaurea sp. 1	m	*Centaurea* sp. *2*	m
	Centaurium ? pulchellum	m	*Cistus* spp.	u
	Conyza albida	m	*Cutandia divaricata*	d D
	Cynodon dactylon	d m	*Cyperus mucronatus*	d, u
	Elytrigia juncea	d R	*Eryngium maritimum*	d D
	Euphorbia paralias	d D	*Holoschoenus romanus*	u
	Holoschoenus vulgaris	m	*Juncus acutus*	m
	Juncus rigidus	m u	*Juniperus macrocarpa*	u
	Launaea resedifolia	d	*Medicago marina*	m
	Nerium oleander	m	*Olea europaea*	u
	Ononis variegata	d	*Otanthus maritimus*	d R m
	Pinus pinaster	p	*Pinus pinea*	p D
	Polycarpon diphyllum	d R	*Polygonum maritimum*	d
	Populus ? nigra	o	*Quercus coccifera*	u
	Quercus ilex	u	*Retama raetam*	d m u
	Salsola kali	d	*Silene succulenta*	d
	Scolymus hispanicus	d, u, m	*Tamarix africana*	m
	Vitex agnus-castus	m	*Xanthium spinosum*	m R

p = planted; d = dune; m = marsh; o = watercourse (oued);
u = afforestation undergrowth; D = dominant; R = rare.

Ile de Kneiss (El Bessila) and adjacent mainland

El Khouala: The main type of vegetation in the shore area is typical of saline marshes and referable mainly to the SARCOCORNIETEA FRUTICOSAE with associations referable to the THERO-SALICORNIETEA in the wetter regions and SAGINETEA MARITIMAE in clearings between the shrubbery. Close to the shore the vegetation consists of a dense growth of halophytic shrubs of which the dominant species are *Arthrocnemum macrostachyum* and *Halocnemum strobilaceum.* Other halophytic shrubs with an important presence are *Zygophyllum album, Limoniastrum monopetalum, Limonium bonduellii* and *Limonium pruinosum.* In the clearings amidst the shrubbery are several small shrubs, particularly *Frankenia thymifolia, Limonium avei* and *Reaumuria vermiculata,* as well as several low growing species particularly *Sphenopus divaricatus* and

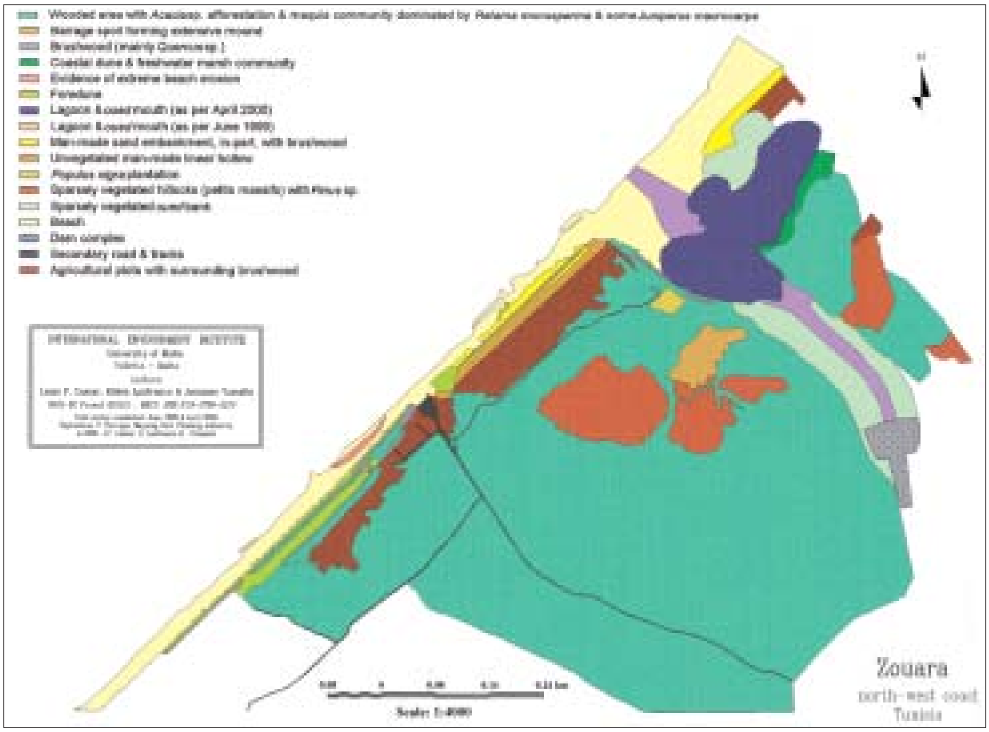

FIG. 2.3.7 *Vegetation map of Zouara*

Filago mareotica but also *Sphenopus ehrenbergii, Aeluropus lagopoides, Cynodon dactylon, Spergularia diandra, Lotus* sp., *Paronychia argentea, Ifloga spicata* and *Loeflingia hispanica.* In the wetter areas close to the shore where there are open pools and gullies, are populations of *Salicornia europaea.* Further back from the shore is a population of *Lygeum spartum* and, in some wetter regions, of *Juncus rigidus.* The halophytic shrubbery, essentially with the same species occurring closer to the shore, was accompanied here by further species such as *Thymelaea hirsuta, Artemisia campestris, Echinochilon fruticosum, Helianthemum lippii, Nolletia chrysocomoides, Asparagus stipularis, Nitraria retusa, Limoniastrum guyonianum, Lycium intricatum, Stipagrostis ciliata* and several composites. Still further from the shore, the terrain becomes disturbed and some areas are under cultivation. Here the halophytic shrubbery becomes sparse and is accompanied by a variety of other species, particularly numerous spiny composites and *Daucus aureus.*

Kneiss island (El Bessila) (Fig. 2.3.8): The vegetational assemblages of the island are essentially similar to those of the shore opposite but with some notable differences. The main assemblages belong to the SARCOCORNIETEA FRUTICOSAE with formations of the SAGINETEA MARITIMAE in the clearings. The dominant species were *Halocnenmum strobilaceum* and *Arthrocnemum macrostachyum,* the former often occurring in extensive pure stands. Close to the water's edge was a stand of *Arthrocnemum (Sarcocnemum) perenne* together with *Halimione portulacoides* and *Suaeda maritima.* Frequent throughout the halophyte scrub were *Limoniastrum*

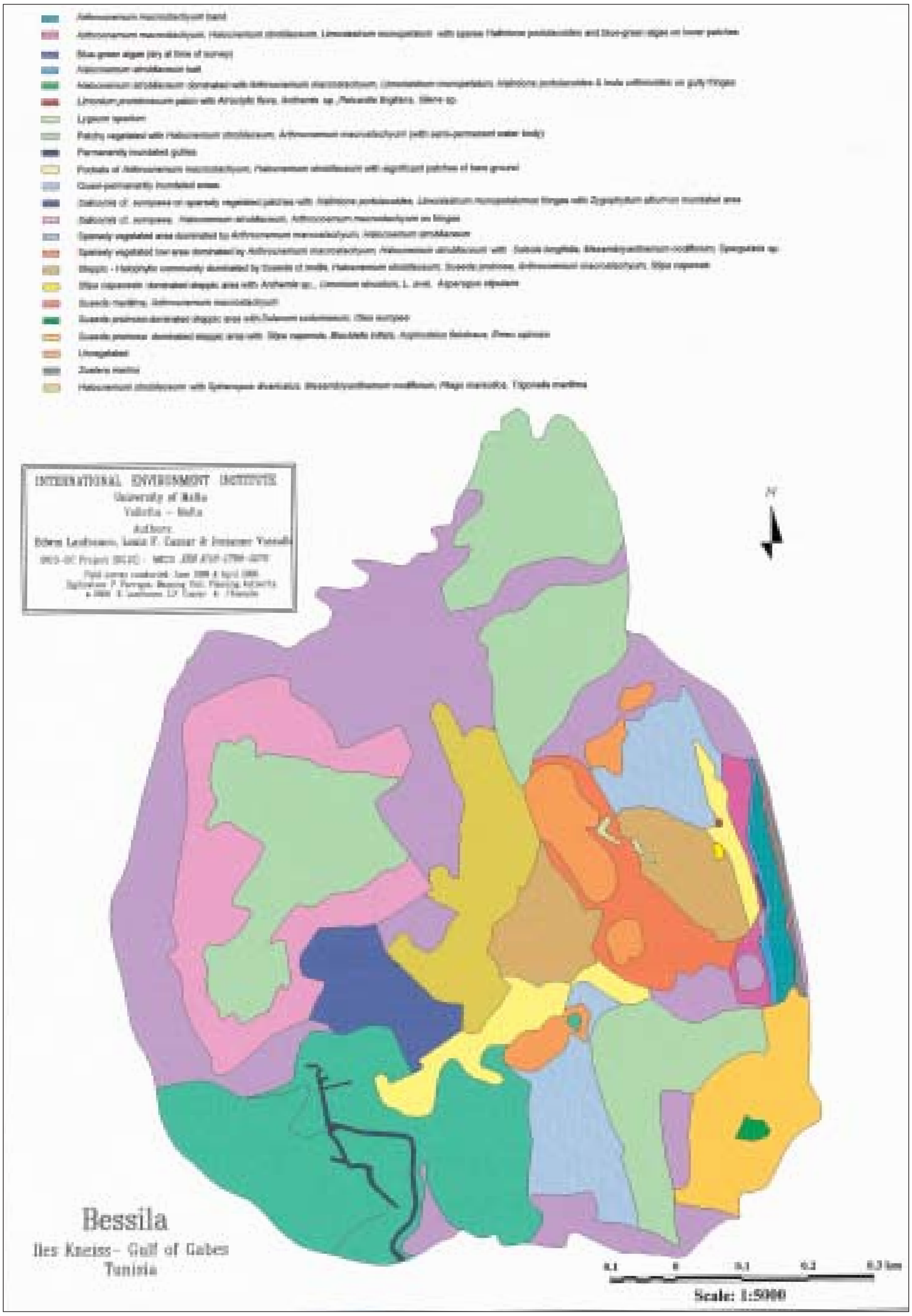

Fig. 2.3.8 *Vegetation Map of the islet of Bessila, Iles Kneis, Gulf of Gabes*

monopetalum, *Zygophyllum album, Limonium sinuatum* (here replacing the closely related *L. bonduellii* of the mainland)*, Limonium pruinosum, Suaeda* cf. *mollis, Darniella* cf. *cruciata*. The more steppic areas included stands of *Suaeda pruinosa, Artemisia herba-alba, Stipagrostis ciliata, Stipa capensis, Allium commutatum, Asphodelus ?fistulosus, Daucus aureus* and undetermined composites, mainly thistles and Anthemidae. Along the water filled gullies were *Halimione portulacoides, Limoniastrum monopetalum* and *Arthrocnemum macrostachyum.* In the clearings were assemblages with *Sphenopus divaricatus, Filago mareotica, Limonium avei, Frankenia thymifolia, Cutandia memphitica, Lotus* sp. and *Spergularia diandra.* Thick crusts of cyanophytes covered areas that were evidently inundated during the wet season. The higher/drier parts include the occasional *Nitraria retusa, Asparagus stipularis, Solanum sodomaeum, Blackiella inflata* and a single olive tree, *Olea europaea.*

2.3.6 *Diptera fauna*

A total of 238 species in 50 families were collected during the whole of this field study (Table 2.3.1). 16 taxa are newly recorded for North Africa; 6 species are endemic to Tunisia, 1 is stenotopic (a site-specific species that occurs exclusively on dunes), at least 52 species were previously not recorded for Tunisia, and 8 species are new to science. These findings serve to underscore the importance of the area under study. More extensive collecting will doubtless unearth more species.

The beach and dunes at Zouara (l/o Nefza) yielded the largest number of species (160). Most of the material recorded consists of widely distributed species that occur commonly in similar habitats in Mediterranean shores and elsewhere. Some of these records are however notable. These include 1 species, which is exclusive to dune habitats, 2 endemic species, 42 species, which are newly recorded for Tunisia, and 2 species which are new to science. Nevertheless, considering its very extensive size, the area is not considered to have a particularly rich dipterous fauna. Some large or important families, such as the Agromyzidae, Bombyliidae, Culicidae, Chironomidae, Dolichopodidae, Hybotidae, Empididae, Simuliidae, and Syrphidae were under-represented. The erosion of the beach, increasing human interference, exten-

TAB. 2.3.1 *Records of Diptera at the MECO sites in Tunisia*

	FAMILY	SPECIES	E	NR	NS
Zouaraa (Nefza)	43	160	2	42	2
Bessila (Kneiss)	25	53	4	7	3
Hachichina	21	41	2	3	6

E = Endemic, NR = New Record, NS = New Species sive cultivation of the fore dunes with introduced plant (*Acacia*) species and the damming up of the Oued Zouara all seem to exert a negative impact on the dune fauna. The consolidated dunes behind the shore have a greater diversity, in part due to the presence of a more varied flora and the abundance of goat dung with its associated fauna.

On the islet of Bessila (Kneiss) 53 species were collected. Of these 4 are endemic to Tunisia, 7 species are newly recorded for Tunisia, and 3 species are new to science. The island is clearly of scientific importance and deserves protection from human interference. The presence of a sizeable population of nesting seabirds with their guano and its associated fly fauna adds interest to the site.

The saltmarsh and steppe at El Khaoula, limits of Hachinina, is also of interest, with 2 endemic, 3 previously unrecorded and 6 undescribed species. Unfortunately, clear signs of human interference were evident at the site. In particular, much of the steppe is being taken over for agricultural purposes, and the marshland up to the coastline is being used for dumping of household refuse and other waste.

2.3.7 *Conclusion*

Environmental issues and impacts: Both sites under study are, in many respects, of significant scientific interest. From the ecological and geomorphological viewpoints, Zouara and Kneiss are ideal locations for investigating their respective dynamic systems. The site at Zouara is most suitable for studying dune morphology in relation to human intervention; it also lends itself suitably for environmental education purposes. Kneiss, on the other hand, is the ideal site for examining and monitoring mudflat dynamics and sediment cycles; it also provides the possibility of further primary research in both geomorphology and ecology, particularly avifauna.

With regard to threats and impacts, both sites appear to be under a significant amount of risk as a result of human activity. In the case of Zouara, the area has been impacted upon following the construction of the dam. In this regard, sediment fluxes have been negatively impaired with serious consequence to the dunes. The beach and adjacent foredunes are also under severe pressure in view of the fact that the area is utilized for recreational/bathing purposes during the summer season. Human presence, in this regard, has contributed to the degradation of various elements, which constitute the coastal belt at Zouara-Nefza.

Other notable elements, which contribute towards the further degradation of the dunes at Zouara and the area in general include:

– the use of brushwood to 'stabilize' the sand. Apart from demonstrating poor management practice, brushwood, once dry, will increase the risk of fire. Moreover, it induces changes in the hydrological system of the dune, by reducing evaporation and thereby altering the characteristics of the dune ridge and slopes. It would also impede the active growth of dune vegetation so important to dune stabilization and development.

- the use of heavy plant machinery for shifting of sand on dunal zone, which disrupts natural aeolian processes;
- the use of alien species for afforestation or species that are planted out of context to the habitat-type in question;
- damage caused by agriculture-related activities such as reclamation of dunal areas for cultivation and the possible use of pesticides and fertilizers, concentrations of which would have a negative impact on the biota present;
- the presence of permanent (concrete) and temporary (timber) constructions on the rear sector of the beach, which are quite harmful to foredune development;
- trampling, disturbance and encroachment in general by visitors to the area.

With regard to potential impacts, the site at Zouara would prove exceedingly vulnerable to increased human presence, particularly if this were to lead to the development of the area for tourism and recreational activities. Any unplanned amenity and infrastructural development, including camping, would probably prove detrimental to the area in general.

In the case of Kneiss islets, impacts include:

- disturbance by local fishermen and visitors alike;
- dispersal of litter, mainly plastics (bags, bottles, etc.), glass and other waste including certain flotsam such as fishing lines, floats with hooks; apart from marring the area aesthetically, such refuse may also entrap, injure or even cause the death of various species of marine fauna (including sea turtles) and small mammals, reptiles and invertebrates on land.

An increase in the islets' popularity for bird watching, for example, coupled by the lack of management frameworks may lead to mismanagement practices and hence result in increased levels of disturbance.

2.4 CASE-STUDY: MALTA SITES CHARACTERIZATION

Josienne Vassallo, Michelle Borg and Louis F. Cassar

2.4.1 *Background*

The Maltese Islands support a number of pocket beaches of varying size, the largest reaching a maximum length of some 1 km or so. There are a total of nine beaches on the Maltese Islands supporting sand dunes or remnant thereof. Five sandy beaches, four of which occur in mainland Malta and one in the island of Gozo, used as a control site, are investigated within the framework of the MECO Project (Fig. 2.4.1). These are:

– Ghadira;
– Ir Ramla tat-Torri (also known as WhiteTower Bay);
– Armier;
– Ramla tal-Mixquqa (also known as Golden Bay); and
– Ramla l-Hamra (also known as Ramla Bay) on Gozo.

2.4.2 *Site characterization*

a. *Ghadira*

Characterization: Ghadira, in the limits of Mellieha Bay, is situated on the

FIG. 2.4.1 *Map of the Maltese Islands showing the location of the MECO study sites:* (1) *Ramla l-Hamra (Gozo),* (2) *Armier,* (3) *Ir Ramla tat-Torri (Torri l-Abjad),* (4) *Ghadira and* (5) *Ramla tal-Mixquqa (Malta)*

Fig. 2.4.2 *Aerial view of Ghadira Bay*

north-eastern coast of the Island of Malta (Fig. 2.4.2). The beach is located between two headlands, the Marfa Ridge and the Mellieha Ridge. Geologically, Ghadira and the surrounding land is composed of Upper Coralline Limestone rock, *tal-Pitkal* Member, with Blue Clay slopes on Marfa Ridge and Upper Coralline Limestone plateaux on either side of the beach.

From the ecological point of view, the importance of Ghadira is, essentially, two-fold, in that it supports:

I) a saline marshland; and
II) a sand dune system.

Ghadira supports the largest remaining saline marshland in the Maltese Islands. With an extent of about six hectares, the saline marshland lies about one hundred metres from the sea at Malta's most extensive beach, Mellieha Bay). The other habitat, as outlined above, is a sand dune remnant adjacent to the saline marshland. Ecologically, the sand dune is highly degraded following years of misuse and habitat mismanagement (see also Fig. 1.4.5B in section 1.4.3).

Both of these habitats are located on the northeastern (terrestrial) extremity of a downthrown limestone block lying between two SE to NW running parallel faults. Ghadira valley is a graben with a downward tilt towards the NE, located between Mellieha Ridge to the south and Marfa Ridge to the north.

Surrounding the beach is an elevated ground that made it possible for alluvial and colluvial materials to deposit into the depression. It is on these deposits that the saline marshland developed. Consequently the marshland's substratum is composed of beach sand towards the NE and alluvial deposit towards the SW.

Vegetation cover: The vegetation of the area is dominated by alien *Acacia* spp., planted some decades ago, and a freshwater community dominated by *Arundo donax*. Dune species are also present, including *Elymus farctus, Sporobolus arenarius, Pancratium maritimum, Euphorbia terracina*, and *Orobanche densiflora* var. *melitensis*. Other species include opportunistic species like *Chrysanthemum coronarium* and *Oxalis pes-caprae* and coastal species like *Tamarix* sp., *Atriplex halimus* and *Juncus acutus*. Besides these, planted species are also present in fairly large number; these include *Pinus halepensis*, *Acacia* spp. and *Eucalyptus gomphocephala*.

b. *Ramla tat-Torri*

Characterization: Ir-Ramla tat-Torri (also known as White Tower Bay) on the northern most tip on the Marfa Peninsula, is located between two headlands. Geologically, the site is composed of Upper Coralline Limestone rock (*Mtarfa* Member). Although human disturbance is highly evident, the beach supports a dune habitat.

Aeolian development is almost continuous along the bay's littoral wherever foredune development is active. The dunes have an acute angle of slope ranging between 12° and 18°. Although the interaction between the beach and the foredune area is evident in terms of sediment flux association, older dune ridges have disappeared following degradation and encroachment mainly by the various land-uses located both on the beach itself and further inland. In this respect, the sediment flux between the beach zone and the foredune area appears to fluctuate from *negative to negative* budget and *negative to positive* budget. The latter scenario, however, seems short-term. On the other hand, the inland input appears to have been negatively affected by encroaching caravans and permanent structures *i.e.*, boathouses and a road.

The valley system occurring on the posterior sector of the dune, and which in effect supplies the beach/dune area with sediment, is extremely shallow and surrounded by agriculture. A principal threat posed at this point is that agricultural land surrounding the *wied* is constantly undergoing reclamation, thus further reducing sediment flow from the valley towards the beach itself. Water catchment is quite extensive, however the new retaining rubble walls enclosing agricultural land along the valley course, will impede sediment transport mechanisms, which convey material seaward.

These boathouses, many of which are illegal and function more like summer residences, dominate the beach and the surrounding landscape. Being permanent, these structures are disturbing the dynamics of this coastal dune. Earlier during the year (2001), a number of boathouses in the Maltese Islands, some of which were located at ir-Ramla tat-Torri l-Abjad, were demolished.

Vegetation cover: The site is mainly dominated by *Eryngium maritimum*, *Elytrigia juncea* together with *Tamarix africana*. Dune species also include *Euphorbia terracina*, *Salsola kali*, *Sporobolus arenarius*, *Cakile maritima, Pancratium maritimum*, *Erodium laciniatum*, *Otanthus maritimus*, *Lotus cytisoides*, *Echinophora spinosa*. The pioneer species on the foredune is *Elytrigia juncea*. Other species include *Arundo donax*, *Oxalis pes-caprae*, *Reichardia picroides* and *Soncus oleraceus*.

A negative aspect with regards to vegetation is the fact that inland weed species, always in competition with dunal vegetation, are constantly spreading. On the other hand, the young tamarisk trees, which had been irresponsibly chopped down during an official beach clean-up, appear to be regenerating slowly and have presently formed a low thicket.

c. *Armier*

Characterization: Another site located on the north of Marfa Peninsula which also supports a dune habitat, albeit exceedingly small in area, is Armier. The beach, composed of Upper Coralline Limestone (*Mtarfa* Member), is located between two headlands, one of which is the headland separating Armier from ir-Ramla tat-Torri. *Wied* Armier provides the main source of freshwater and, consequently, sediment fluxes in the bay.

Vegetation cover: The dominant species on site are *Elytrigia juncea* and the weedy species *Oxalis pes-caprae*; the latter being an invasive alien. In addition to *E. juncea*, the Armier dune supports a dunal flora including: *Sporobolus arenarius*, *Cakile maritima*, *Euphorbia terracina*, *Lotus cytisoides*, *Scolymus hispanicus* and an exceedingly rare population of *Calystegia soldanella*. The latter species, thought to be extinct from the Maltese Islands, was rediscovered in 1995 on the 'foredune' zone. A fairly significant, but nonetheless vulnerable, population was confirmed to be present on site in recent years. In view of the bay's popularity, the species is seriously threatened. Another species in the area includes *Arundo donax*, which grows along the valley's watercourse.

d. *Ramla tal-Mixquqa*

Characterization: Ir-Ramla tal-Mixquqa, also known as Golden Bay, is located on the western side of Malta in the limits of Ghajn Tuffieha (Fig. 2.4.3). The site is situated between two Upper Coralline Limestone (*tal-Pitkal* Member) headland plateaus, Ghajn Tuffieha and in-Nahhalija. The coastal zone in the environs of Mixquqa is dominated by a number of headlands and embayments supporting a number of small pocket beaches, one of which is Mixquqa.

A highly degraded foredune with complete absence of vegetation cover dominates the beach. Although the beach itself is quite flat, the dune area exhibits a sharp angle of slope of some 32°. The absence of vegetation cover on the foredune area is to such an extent that it nearly resembles a back-beach assemblage rather than an actual foredune. The only vegetation present on this mass of sand appears to be a regenerating stand of *Arundo donax*.

For descriptive purposes, it was thought pertinent to sectionalize the area into three entities:

I) the watercourse;
II) the dune proper; and
III) the back-beach deposit.

FIG. 2.4.3 *Aerial view of Ghajn Tuffieha region*

Watercourse: From the geomorphological point of view, the watercourse is highly degraded. There are few business outlets at Mixquqa, however, a kiosk, constructed on an elevated wood platform over the fluvial source, has had some effect on the dynamics of the system.

Dune proper: The dune ridge itself represents a well-consolidated body that has, over the years, been taken over by an extensive band of halophytic vegetation. An angle of slope of approximately 32° was registered on the dune ridge, with some places being more acute. A well-visible Upper Coralline Limestone outcrop in the lower part of the dune acts as support to the physical structure of the dune.

Dominant species on the dune ridge include *Inula crithmoides* and *Senecio bicolor* together with fairly extensive coverage of *Tamarix* sp., some of which have attained significant dimensions. It is assumed that the mature, naturally occurring tamarisks form the climactic coastal sequence. Beyond the ridge (topmost area) is an ancient rubble wall, constructed at a time when agriculture was still practiced in these parts.

Although the dune contains a number of species typical of dunal habitats, it shows signs of disturbance, namely from the point of view of litter, since the prevailing wind carries waste to the dunal zone, as also in terms of alien species.

An extensive growth of *Carpobrotus edulis* is slowly taking over the entire dune area. Being an invasive alien species, *C. edulis*, forms extensive carpets that smother dune vegetation and hinders aeolian depositional processes. A species indicating degradation of the dunal community is *Lavatera arborea*, which is fairly common.

FIG. 2.4.4 *General view of Ramla l-Hamra*

Dunal vegetation community consists of *Cakile maritima*, *Pancratium maritimum*, *Echium arenarium, Elytrigia juncea*, *Sporobolus arenarius, Eryngium maritimum*, *Scolymus hispanicus* and *Medicago marina*. Other species include *Medicago litoralis, Chicorium spinosum, Inula crithmoides* (on upper beach part) and *Oxalis pes-caprae*.

Back-beach deposit: The back-beach deposit, reaching an angle of 13°, is dominated by a consolidated dune on which wooden stairs have been constructed. Within this zone, *Bembix occulata* (Insecta – Hymenoptera) was present in good number during the time of survey, burrowing in the harder substrate. Human disturbance in this area is evident mainly during the summer season.

On the southern side of ir-Ramla tal-Mixquqa, the angle of slope ranges between 24° and 25° to the foot of the cliff (scree, boulders detached from above Upper Coralline Limestone plateau). This area may well have accommodated a climbing dune in the past.

Vegetation cover: The dominant species on site are *Elytrigia juncea*, *Pancratium maritimum* and *Tamarix* sp. In addition, other dune species include *Cakile maritima*, *Sporobolus arenarius*, *Eryngium maritimum*, *Scolymus hispanicus*, *Medicago marina* and *Echium arenarium*. Other species include *Arundo donax*, *Silene colorata*, *Glaucum flavum*, *Lavatera arborea*, *Medicago litoralis*, *Chicorium spinosum*, *Inula crithmoides* and *Oxalis pes-caprae*.

e. *Ramla l-Hamra*

Characterization: Ramla l-Hamra lies on the northern coast of the island of Gozo at the mouth of a valley known as *Wied tar-Ramla* (Fig. 2.4.4). The dunes at Ramla l-Hamra are the best example of such a habitat type in the Maltese Islands. Although like the rest of the dunal areas, these have been subjected to various anthropogenic impacts, the Ramla dune system is quasi-intact and still supports most of the typical dune flora and fauna. It is on the basis of species richness, ecosystem stability an active morphological dynamics that the coastal dunes at Ramla l-Hamra are the most important dune system on the islands.

The beach is located between two Upper Coralline Limestone headlands on which are the settlements of Xaghra and Nadur. Geologically, Ramla beach lies on Upper Globigerina Limestone rock, however sediment supply to the beach originates from the erosion of the Upper Coralline Limestone plateaux escarpments and boulder screes, and Greensand, through climatic factors, wave action and terrestrial run-off. Ramla is considered as very dynamic in terms of sediment budget and supply. Terrestrial run-off, the main source of sediment supply, comes from a number of valley systems, namely Wied tar-Ramla, Wied il-Harraq and Wied il-Pergla. In fact, during the wet season run-off from the Wied tar-Ramla watercourse reaches the sea forming a shallow gully, carrying sediment into the bay for a number of weeks.

Vegetation cover: Ramla l-Hamra still supports typical dune vegetation. The dune system's main sand binders are *Elytrigia juncea* and *Sporobolus arenarius*. Ramla also supports vulnerable, rare or endangered dune flora that include: *Echinophora spinosa*, *Pancratium maritimum*, *Eryngium maritimum*, *Euphorbia paralias*, *Euphorbia terracina*, *Euphorbia peplis*, *Medicago marina*, *Cakile maritima*, *Cutandia maritima*, *Pseudorlaya pumila*, *Ononis variegata*, and a very rare sand-dwelling mushroom *Montagnites arenaria*.

Apart from the sand dune habitat, a number of other biotic communities occur within the Ramla region. These include:

- Freshwater wetland community ~ supporting beds of *Arundo donax*, *Phragmites australis* and *Typha domingensis*;
- *Crithmo-Limonietum* association ~ dominated by halophytes, *Inula crithmoides* and *Limonium melitensis*;
- *Ononis natrix* garigue ~ dominated by *Ononis natrix*, *Asparagus aphyllus*, *Dittrichia viscosa*, *Pancratium maritimum* and *Cyperus capitatus*; and
- Disturbed ground, mainly found in areas mostly liable to anthropogenic disturbance such as trampling and vehicle access.

2.4.3 *Management Options for Ghadira, Ramla tal-Mixquqa, Armier, Ir-Ramla tat-Torri and Ramla l-Hamra*

Introduction

The predominant use of these beaches within the Maltese Islands is related to bathing. There are no management schemes currently in place that regulate the type and level of activities that can occur within sandy beaches. Separate measures attempting to regulate one form of activity or another have been adopted such as beach cleaning operations and kiosk development.

The objective of this section is to identify those management options for land based activities within the sandy beaches under study that allow for the continual use as recreational areas whilst aiming to safeguard the beaches themselves as natural systems. It is not the scope of this manual to look into water-related activities or the submerged areas of these beaches.

Existing Uses and Activities

The land uses and activities occurring within these beaches that will be considered in this section include:

- Sunbathing;
- Barbeques;
- Beach cleaning;
- Kiosks and Restaurants;
- Placement of beach paraphernalia, *e.g.*: paddleboats/sun beds;
- Construction of concrete walls along water's edge;
- Road construction.

The main problems that affect these sandy beaches emanate from the fact that they are used extensively in the summer time for bathing purposes. The promotion of the Maltese Islands as a sun and sea tourist destination has led to the development of inappropriate structures within these areas. The aim of improving access to these areas has led to road construction at the back of beaches (*e.g.* Ghadira and Armier), thus affecting sediment transport. Concrete boundary walls around the beaches as well as the placement of concrete along the beach for the provision of additional beach space (*e.g.* Ghadira) may also affecting beach dynamics.

The provision of refreshments for beach users was translated into the construction of large-scale restaurants on or adjacent to the sandy beaches taking up space for bathers as well as hindering beach processes. In addition to these structures, mobile kiosks are also placed on the beaches to provide both refreshments as well as beach equipment such as deckchairs, umbrellas and paddleboats for hiring. In recognising the importance of the dune systems in Ramla Bay, Gozo, measures were taken in the mid-1990s to remove the kiosks from the beach and relocate them in an adjacent area.

Another activity associated with recreation is that of beach cleaning. The accumulation of *Posidonia oceanica* remains on sandy beaches is considered to be aesthetically unpleasing to beach users. Consequently beach cleaning operations are initiated in mid-April/May before the tourist season. The removal of these *Posidonia* remains prevents the banquette system from developing thus eliminating the protective function it gives the beach against erosion. With the exception of Ramla Bay in Gozo, the removal of *Posidonia* remains is conducted by mechanical means. In addition trucks and other vehicles are driven onto the beach itself during the cleaning of litterbins.

Proposed Solutions

The management options for these areas can be dealt with on two levels. The short-term solution is to adopt a beach management system that controls issues relating to beach cleaning and beach activities. The long-term solution is to address existing structures.

Beach Management: The adoption of a zoning scheme is ideal to direct the spatial allocation of activities on the beach with the aim of prohibiting access to the sand dune areas. The zoning scheme should also identify sunbathing and barbeque areas. Adequate numbers of appropriately designed litterbins should be provided. The zoning scheme should provide for the potential provision of other facilities such as showers/toilets in accordance with the EU Blue Flag system. As much as possible such facilities should be located at the edge of the beach, preferably not on the sand itself.

Beach cleaning: A set of guidelines need to be drawn up to direct how beach cleaning operations of both *Posidonia* remains as well as litterbins, are to be undertaken. With respect to *Posidonia* remains, manual removal of material with rakes should replace the mechanical use in practice today. The removal of these leaves should start later, around late May/June to allow the protective function of the banquette system to continue.

With respect to litterbins, the collection point for disposing material to dump trucks should be located outside the beach itself.

Vehicular Access: No vehicles should be allowed onto the beach. Access points to emergency vehicles should however be indicated.

Existing Structures

Kiosks/Restaurants

The number and location of temporary kiosks should be revised to identify the acceptable quantity to service beach users. Any of the existing structures located on the beach itself, particularly those threatening the development of dune systems should be removed. Their resizing to smaller structures and relocation outside the beach area should be the main objective.

Roads/boundary walls

Those structures that are detrimental to the dune system should ideally be removed. These include concrete steps at Mixquqa, low boundary wall and road at Armier as well as the road cutting across the beach system at Ghadira. The major obstacle that is not likely to be removed is the arterial road at Ghadira as this is the access point to the ferry terminal at Cirkewwa.

To conclude, all of the management solutions identified require an assessment that identifies the financial package needed for their implementation. Most of the solutions concerning beach activities are achievable within the short-term, however the costs for relocating existing structures will be the major hurdle for implementing a management system that secures the long-term protection of these beaches.

2.5 CASE-STUDY: SMIR LAGOON, MOROCCO

LES MARAIS DE SMIR: UN MILIEU FRAGILE D'INTÉRÊT REMARQUABLE

Abdellatif Bayed et Mohamed-Aziz El Agbani

2.5.1 *Les marais les plus occidentales du bassin méditerranéen*

Les marais de Smir (Fig. 2.5.1) se localisent dans la péninsule tingitane à l'extrémité Nord-Ouest du continent africain. C'est autour de cette péninsule que des masses d'eaux marines différentes se côtoient et s'échangent à travers le Détroit de Gibraltar permettant ainsi le renouvellement des eaux de la mer Méditerranée. Ici le Maroc ne se trouve qu'à 14 km du continent européen et les paysages naturels du nord marocain et du sud espagnol marquent une histoire géologique commune et une évolution du relief et des paysages comparable, modelés par les hommes ayant occupés ces deux rives depuis bien longtemps.

Les marais de Smir s'étendent de la localité de M'diq jusqu'à l'embouchure de l'Oued Smir et se trouvent à quelques 30 km au Nord de la ville de Tétouan. Ils bordent la façade méditerranéenne du Maroc à quelques 25 km du Détroit de Gibraltar sur une côte sensiblement de même longueur orientée Nord-Sud et délimitée par le promontoire de Koudiat Taïfour au Sud et par la presqu'île de Sebta au Nord. Avant

Fig 2.5.1 *Vue générale du site d'étude montrant la lagune de Smir, les marais, la localité de M'diq et le promontoire de Koudiat Taïfour*

la mise en place d'aménagement, ces marais représentaient la zone d'inondation de l'Oued Smir avant son débouché en mer.

Sur toute la façade méditerranéenne marocaine, on ne rencontre un tel type de zone humide et une telle diversité d'habitats qu'au niveau de deux localités: 1. l'embouchure et marais de l'Oued Smir à l'extrémité occidentale; 2. l'embouchure et marais de l'Oued Moulouya à l'extrémité orientale.

2.5.2 *Un bassin versant côtier*

D'une superficie de 100 km^2, le bassin versant de l'Oued Smir domine majestueusement le paysage qui se présente en une succession de reliefs parallèles à la côte avec des altitudes décroissantes d'Ouest en Est. Le massif calcaire appelé aussi dorsale calcaire culmine à plus de 800 mètres et se trouve dépourvu de végétation. Il est suivi d'une dépression longitudinale d'altitude bien plus faible (200 mètres) qui constitue le piémont immédiat de cette dorsale. Le relief regagne ensuite de l'altitude au niveau des basses montagnes dont les sommets arrondis atteignent 300 mètres. Ce relief perd progressivement de son altitude en direction de la mer pour former un secteur relativement bas occupé par les marais et la lagune de Smir. Cet ensemble est bordé côté mer par une dune formant un cordon littoral séparé de la mer par une plage sableuse. La confluence de plusieurs cours d'eau dans le piémont immédiat de la dorsale calcaire forme l'Oued Smir qui, a quelques kilomètres de son embouchure, développe son lit entre deux massifs collinaires du Jbel Zemzem au Nord et le massif de Rachchaka – Koudiat Taïfour au Sud.

Les caractéristiques du climat méditerranéen qui règne dans la région permettent de le classer dans l'étage bioclimatique humide. Les précipitations à Tétouan et M'diq sont généralement supérieures à 600 mm/an et représentent près du double de la moyenne nationale. Depuis la saison 1998-1999 et jusqu'à la saison 2000-2001, les précipitations ont montré une diminution significative, comme pour l'ensemble du territoire marocain, et étaient légèrement supérieures à 400 mm/an contre des années humides avec une pluviométrie pouvant atteindre 800 mm/an. Les pluies sont très abondantes durant la période novembre-janvier alors que la période sèche, sans précipitations ou avec précipitations réduites, s'étend de juin à septembre. La moyenne des températures à Fnideq varie entre 11°C en janvier et 28°C en août.

2.5.3 *Lieu de rencontre entre eaux continentales et eaux marines*

L'alimentation en eaux douces des marais et de la lagune de Smir ont subit de profonds changements depuis la construction d'un barrage sur l'Oued Smir entré en fonction en 1991. Avant la mise en place de ce barrage, l'Oued Smir représentait la principale source en eau douce de ce complexe dont le débit dépassait 40 l/s en moyenne par an (année normale) avec un maximum qui pouvait atteindre 75 l/s. Notons que ce débit pouvait atteindre 640 m^3/s pendant les périodes de crues. Le barrage est construit sur la limite qui sépare la dépression longitudinale d'altitude des

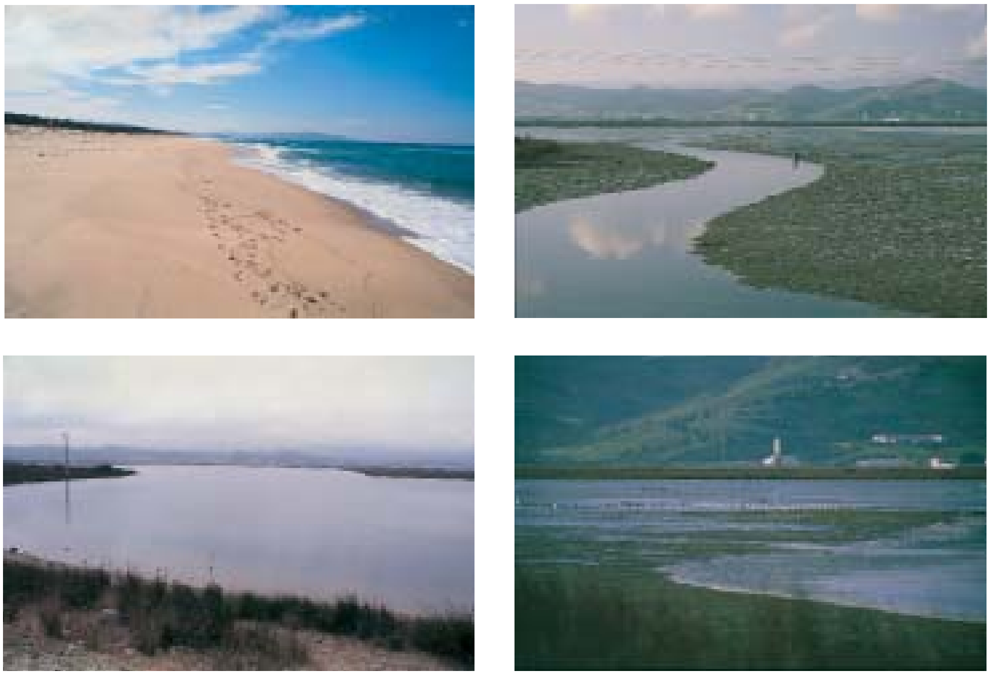

FIG 2.5.2 *L'étendu de la plage et la lagune de Smir*

basses montagnes, son mur a une hauteur de 45 mètres et développe une surface de retenue de 475 hectares permettant de garder 43 millions de mètres cubes. Les eaux de ruissellement et la nappe phréatique sont les autres sources en eau douce qui alimentent les marais et la lagune. Bien que certains puits soient creusés à proximité de la lagune où pénètrent les eaux marines aucun contact ne semble être établi entre nappe phréatique et eau marine. Il est probable que la nature envasée et compact du fond de ce plan d'eau limite les échanges entre ces eaux.

Les marais sont parcourus de chenaux permettant aux eaux de ruissellement d'atteindre la lagune située dans la partie nord de ce complexe (Fig. 2.5.2). Actuellement l'alimentation en eaux d'origine continentale provient principalement des rejets d'eaux usées de la ville de M'diq située à 5 km de la lagune. Le surplus des eaux usées, ne pouvant pas être traitées par une unité locale est rejeté à l'extrémité sud des marais avant d'aboutir dans la lagune à travers un réseau de chenaux qui sillonnent un couvert végétal assez dense permettant l'épuration naturelle de ces eaux qui enrichissent le milieu en matière organique et en polluants. Les chenaux convergent et forment un chenal principal permettant de faire déboucher les eaux d'origine domestique dans la lagune. Ceci a favorisé le développement d'une importante roselière qui joue un double rôle; elle permet l'épuration des eaux usées d'une part et constitue un refuge pour la reproduction de plusieurs populations remarquables d'oiseaux d'eau, d'autre part. Il est à noter que le complexe touristique attenant à l'embouchure déverse aussi ses eaux usées dans la lagune et aucun traitement préalable n'a été mis en évidence. Ceci a pour effet l'enrichissement en matière organique du secteur nord de la lagune.

Les bouleversements du régime hydrologique des marais, en général et de la lagune en particulier, se trouvent encore accentués par la modification qui a touché la débouchée de l’Oued Smir en mer. En effet, depuis la construction d’un port de plaisance et du complexe touristique y attenant, la communication avec la mer à travers le port est devenue permanente. Ce contact régulier par le biais du flux et reflux de la mer s’est traduit par une modification progressive des conditions physico-chimiques des eaux et par là un changement significatif des composantes de la biodiversité dans la lagune et les marais. Le déficit en apport d’eau douce a eu pour conséquence une extension d’habitats supportant une forte salinité, notamment la salicornaie au dépend de ceux qui ne se développent normalement qu’en eau saumâtre à douce (jonchaie, phragmitaie et typhaie).

Avec une profondeur maximale de 2,5 mètres, la lagune dont la superficie actuelle est de 0,5 km^2 présente des dimensions assez réduites, par rapport à des situations antérieures où elle occupait la quasi totalité de la surface actuelle des marais. La lagune débouche dans un port et les échanges avec la mer sont permanents et dépendent uniquement de l’amplitude de la marée. Dans ce secteur de la Méditerranée, la marée est de type semi-diurne dont l’amplitude est significative, de l’ordre de 1 mètre environ. La salinité de l’eau marine y est de 37‰ et la température peut atteindre 24°C en été contre 17°C en hiver. La digue construite dans le but de limiter la pénétration de l’eau de mer dans la lagune ayant cassée, l’eau marine pénètre dans la lagune et en homogénéise les valeurs des composantes physico-chimiques (température, salinité, oxygène dissous, pH, etc.). En été et pendant le flot, l’eau marine inonde la lagune et progresse dans les marais à travers le chenal principal qui va ainsi permettre l’extension des masses d’eaux salées qui vont conquérir progressivement les zones intérieures des marais. Pendant le jusant, un zonage des paramètres physico-chimiques apparaît; ainsi les eaux sortantes du chenal principal et celles occupant les endroits les plus reculés de la lagune ont une température élevée pouvant atteindre 29°C. La salinité suit le même scénario puisque les eaux entrantes ne dépassent pas 37‰ alors que les eaux sortantes atteignent 40 ‰.

2.5.4 *Lieu de fortes diversités biologiques, d’habitats et de productivités*

Mesurer le niveau de la biodiversité (diversité biologique) d’un milieu est un outil d’estimation de son équilibre et de son évolution. Les marais et la lagune de Smir recèlent un grand nombre d’espèces végétales et animales qui présentent un intérêt pour la biodiversité marocaine, nord-africaine ou méditerranéenne. Ce qui permet à ce complexe écologique de revêtir une importance majeure. Certaines de ses originalités lui ont valu qu’il soit classé, dans le cadre de l’Etude Nationale sur les Aires Protégés, comme Site d’Intérêt Biologique et Ecologique (SIBE) parmi les 29 sites littoraux retenus (Eaux et Forêts, 1995).

Dans le cadre du projet MECO, l’originalité de ce site a été renforcée par la découverte d’une flore très riche à l’image de la diversité des conditions écologiques qui règnent sur l’ensemble de ce plan d’eau. Pas moins de 14 espèces d’algues et 3 espèces de phanérogames tapissent le fond de la lagune de nature sableuse et sablo-vaseuse.

Les prélèvements étaient réalisées par plongée libre et les algues et phanérogames ont été récoltés à la main en veillant à récupérer l'ensemble de la plante. L'ensemble a été conservé puis ramené au laboratoire pour identification. Dans chaque station le taux de recouvrement par la végétation a été estimé et évalué.

Les herbiers de phanérogames (plantes à fleurs se reproduisant par germination des graines comme les formes homologues terrestres) sont des habitats remarquables et privilégiés. En mer, ces herbiers sont particulièrement connus des pêcheurs en raison des captures potentielles de poissons, coquillages et crustacés qu'ils peuvent y réaliser. Parmi les phanérogames rencontrés figure *Zostera marina* qui, en Méditerranée, a vu la réduction des surfaces qu'elle occupe et la dégradation de ses biotopes préférentiels en rapport avec le développement des aménagements côtiers. Son extension en Méditerranée est limitée et est relativement rare en Afrique du nord. Cette espèce est actuellement protégée par de nombreuses conventions et accords internationaux. Sa présence dans la lagune de Smir confère à celle-ci une importance majeure.

Les assemblages écologiques des algues et des phanérogames sont en rapport avec les conditions écologiques différentes et il est possible de distinguer entre groupes d'espèces qui préfèrent s'installer dans les zones bénéficiant d'arrivées d'eaux douces et les phanérogames qui occupent une position médiane en tolérant des dessalures, mais qui abondent particulièrement dans les zones franchement marines en association avec des algues.

Le macrozoobenthos qui regroupe les animaux vivant sur le fond ou enfouis dans le sédiment et dont la taille est supérieure à 1 mm est un outil complémentaire permettant de mesurer l'état de santé du milieu. En effet, ce compartiment de la composante biotique de l'écosystème intègre relativement bien les fluctuations des conditions du milieu et peut révéler sa tendance à court terme et à moyen terme. Il constitue aussi un maillon fondamental dans la chaîne trophique puisqu'il est une source de nourriture essentielle pour de nombreux consommateurs de rangs supérieurs, en particulier les Poissons et les Oiseaux. Tout changement qui touche le milieu, va influencer de façon plus ou moins proportionnelle sur le fonctionnement du compartiment benthique (phytobenthos et zoobenthos), ce qui induit des modifications aux niveaux supérieurs. En somme, la macrofaune benthique constitue un outil de choix et un bon indicateur de l'état de l'environnement des écosystèmes côtiers.

La récolte de ce compartiment a été approchée par un plan d'échantillonnage permettant de prélever l'ensemble des taxons présents et se trouvant dans tous les types d'habitats de la lagune et de la plage adjacente. Le moyen de prélèvement est un carottier de 12,5 cm de côté et le volume total échantillonné par station est de 625 cm^2 (1/16 m^2). Après tamisage sur une toile de 1 mm^2 de vide de maille, les échantillons sont ramenés au laboratoire où sont réalisés tri, identification, comptage et observations biologiques. Pour caractériser le substrat, des prélèvements de sédiment sont réalisés parallèlement à cet échantillonnage.

Dans la lagune de Smir, la macrofaune récoltée se répartit en 32 taxons. Trois groupes zoologiques constituent l'essentiel de ce macrobenthos animal et représentent plus de 84%: mollusques (5 espèces), polychètes (10 espèces) et crustacés (12 espèces). En raison de leur position médiane dans le réseau trophique, ils donnent une idée assez précise sur les conditions du milieu (température, salinité, éclairement, nature du fond, oxygène dissous, etc.) et sur le type de nourriture consommée qu'il s'agit de macrophytes ou de microorganismes et sur l'état de l'équilibre du milieu. Ici, la macrofaune est dominée successivement par les crustacés, suivis des polychètes, puis des mollusques. La densité de ces animaux peut atteindre 16000 individus par mètre carré.

Les plantes supérieures des marais de Smir sont nombreuses et diversifiées. Pas moins de 88 taxons sont reconnues et sont pour l'essentiel des formes dites hygrophytes qui représentent environ 50% de l'ensemble des hygrophytes des zones humides méditerranéennes marocaines. Cette grande diversité est comparable aux plus importantes zones humides marocaines de la façade atlantique: 80 espèces à Merja de Sidi Boughaba et 120 espèces à Merja Zerga. Les principaux facteurs intervenant dans la répartition de la végétation de cette zone sont la submersion, la charge organique et la salinité.

La végétation des marais composée de formations basses denses ou clairsemées et d'autres de moyennes et grandes tailles (roselières) développe de nombreux habitats et permet ainsi à une large gamme d'espèces d'oiseaux de s'y reposer, s'y nourrir et s'y reproduire. Cette diversité biologique, de types d'habitats ainsi que l'importante productivité a conféré à cette zone un cachet de zone humide d'importance internationale sur le plan ornithologique, plus particulièrement en ce qui concerne les espèces d'oiseaux d'eau.

En effet, les marais de Smir constituent la première zone humide sur le sol africain que les oiseaux européens et eurasiatiques empruntant la voie de migration occidentale rencontrent juste après la traversée de la Méditerranée lors de la migration postnuptiale. De la même manière, ces marais constituent un point de passage privilégié et une zone d'escale de choix pour ces mêmes oiseaux lors de leur chemin de retour vers leurs quartiers de reproduction et ceci au cours de la période de migration prénuptiale. Une partie de ces populations peut même y passer toute la mauvaise saison durant la période hivernale. Il faut noter également l'importance des habitats de ce complexe (dunes, végétation dunaire, roselière, sansouire,...) pour la reproduction d'un certain nombre d'espèces d'oiseaux. A titre d'exemple, cette zone représente l'unique localité marocaine où se reproduit régulièrement une colonie de Spatule blanche (*Platalea leucorodia*), espèce menacée et protégée à l'échelle mondiale (Fig. 2.5.3).

2.5.5 *Aménagements et impacts des activités humaines*

Plusieurs activités humaines menacent ce complexe depuis déjà quelques décennies: pâturage, coupe de végétation, occupation agricole, urbanisation, rejets d'eaux usées, perturbation du rythme des marées... Ces activités ont largement contribué à la dégradation de ce milieu.

La région de Restinga-Smir a connu de très nombreux aménagements côtiers qui ne

FIG. 2.5.3 *Une colonie de Spatule blanche* (Platalea leucoradia) *qui se reproduit régulièrement sur la dune de Smir*

s'inscrivaient pas dans une approche globale et ne bénéficiaient pas d'un schéma directeur d'aménagement de ce secteur très touristique de la région. Le plus édifiant de ces exemples est la construction d'un complexe balnéaire et d'un port sur l'embouchure même de l'Oued Smir et la déviation de celle-ci qui ne bénéficie plus de la présence de la dune en tant que structure régulatrice de l'écoulement des eaux douces, d'une part, et de la pénétration des eaux marines, d'autre part. Avec la mise en place du port, les échanges entre mer et lagune sont devenus réguliers avec une prépondérance des eaux marines qui pénètrent de plus en plus dans la lagune et les marais. Avant la mise en place du barrage et du port, la salinité ne dépassait pas 5‰ contre 37 à 40‰ actuellement et on assiste à une *salinisation* de la lagune qui évolue d'une lagune de type estuarien à une lagune de type neutre. En pénétrant dans les marais, les eaux marines contribuent au développement des salicornes et des formations halophytes au dépend de formations originelles associés à la dominance des eaux douces. Cette spéciation de l'écosystème aboutit progressivement à la réduction irréversible de la biodiversité végétale.

La mise en place du barrage a encouragé les riverains des zones avales de l'Oued Smir à assécher des terrains jadis inondables de l'oued et de la périphérie des marais pour y développer des exploitations agricoles qu'ils enrichissent avec des engrais et utilisent des pesticides, lesquels produits aboutissent inévitablement dans les marais et la lagune pour se déverser en mer. Le milieu naturel se trouve ainsi modifié par l'extension de cultures qui s'orientent de plus en plus vers le maraîchage et dont l'irrigation se fait par pompage de la nappe phréatique. Ce qui conduit, avec la retenue des eaux de l'Oued Smir, à une baisse du niveau de la nappe phréatique d'autant plus sollicité que la sécheresse est de plus en plus fréquente et sévère.

L'élevage se trouve aussi affecté, car les agriculteurs abandonnent de plus en plus les races locales en choisissant des races laitières dont l'élevage se fait dans des étables, alors que les races locales pouvaient pâturer dans les marais. Les construction d'étables se multiplient dans les marais et plusieurs pistes surélevées en digue ont été installées dans le but d'accéder aux batteries d'élevage et aux maisons secondaires. Ces digues empêchent une circulation adéquate de l'eau dans les marais.

La capacité de traitement de la station d'épuration de M'diq se trouve actuellement dépassée par l'essor démographique et l'exode rural qui ont transformés cette localité en une véritable ville. Durant la saison estivale, la population de M'diq se trouve multipliée par un facteur 10 et les rejets liquides dans les marais sont très abondantes et dépassent même la capacité de charge du milieu. Les marais subissent ainsi un envasement progressif suite à l'accumulation de la matière organique conduisant à l'eutrophisation du milieu et à l'installation de conditions anoxiques. Un système nuisible à la santé des habitants (pullulation d'insectes nuisibles et des moustiques en particulier; odeurs désagréables, disparition du couvert végétal, etc.) risque de s'installer ce qui conduit à une mobilisation soutenue des autorités locales et tout particulièrement ceux responsables de la santé public.

L'absence ou la non mise en œuvre d'un plan directeur d'aménagement de M'diq, se traduit sur le terrain par la multiplication anarchique de lotissements qui non seulement empiètent sur la zone humide, mais ne dispose pas de cadre adéquat pour l'installation de familles (absence de tout à l'égout, risque éminent d'inondations, salubrité douteuse des zones avoisinantes par l'extension du volume des rejets domestiques).

2.5.6 *Plan d'aménagement et de gestion, revitalisation et équilibre des systèmes*

Le barrage de Smir est vital pour la région et permet d'alimenter en eau potable les villes de Tétouan, M'diq, Fnideq et la zone côtière de Restinga-Smir. Le développement durable implique des mesures correctives à mettre en place de façon régulière. Le plan d'aménagement et de gestion de cette zone entrepris dans le cadre du projet MECO est une réponse qui se veut prospective se basant sur un diagnostic exhaustif permettant la définition des actions à entreprendre après une large concertation avec les acteurs et de s'assurer de leur implication dans le processus identifiés.

Les actions proposées dans le cadre du plan d'aménagement et de gestion du complexe de Smir aboutiront sans doute à un rétablissement de l'équilibre de l'écosystème. La réussite de ce plan est tributaire d'un certain nombre de conditions, notamment:

1. Une bonne information et sensibilisation de l'ensemble des partenaires ayant des intérêts au niveau de ce complexe avant d'entreprendre toute action; 2. L'établissement d'un climat de confiance entre décideurs, partenaires socio-économiques et population locale; 3. Participation de la population locale aux prises de décision et aux programmes de gestion concernant le complexe avec proposition de mesures compensatoires adéquates.

2.5.7 *Les oiseaux indicateurs de la qualité du milieu*

Les oiseaux se trouvant à un niveau supérieur de la chaîne trophique constituent un bon indicateur de la qualité du milieu. En effet, leur installation ou disparition est un outil de diagnostic souvent utilisé dans l'évaluation des zones humides. Dans le cas des marais de Smir et des environs immédiats, la diversité des grands types d'habitats (lac de barrage, marais d'eau douce, roselière, marais d'eau saumâtre, sansouire, dune boisée, plage sableuse,…) explique la grande diversité ornithologique de cette zone. En plus, ce peuplement d'oiseaux comprend un certain nombre de populations ayant une importance nationale et internationale.

1. **Lac de Barrage**: la création de cette pièce d'eau a constitué une importante zone de refuge pour plusieurs populations d'oiseaux d'eau, particulièrement du groupe des Ansériformes (Oies et Canards) durant la période d'hivernage. En effet, pendant les cinq dernières années (1996-2001) le peuplement hivernant d'Ansériformes est de plus en plus diversifié et ses effectifs sont de plus en plus nombreux. Les valeurs enregistrées montrent une croissance régulière allant de 5000 individus à 14000 oiseaux recensés en janvier 2000. De ce fait, ce lac de barrage est considéré parmi les cinq meilleures zones humides marocaines en ce qui concerne l'hivernage des Anatidés. Il est considéré comme site d'importance internationale pour l'hivernage du Canard Souchet *(Anas clypeata)* puisqu'il y accueille plus de 1% de la population régionale du Paléarctique occidental et répond ainsi au critère de sélection de la convention de Ramsar.

2. **Marais d'eau douce et Roselière**: Zone parmi les rares localités du Maroc pour la reproduction d'un certain nombre d'espèces rares et ou menacées d'oiseaux d'eau telles que l'Héron pourpré, l'Héron Bihoreau, l'Héron crabier, le Busard des roseaux.

3. **Dune boisée:** Première colonie pour la reproduction de la Spatule blanche *(Platalea leucorodia)* au Maroc au niveau de la dune de la plage de Smir (Fig. 2.5.3). C'est une colonie mixte d'une quinzaine de couples de Spatule blanche, 500 couples d'Héron garde-bœuf (*Bubulcus ibis*), 50 couples d'Héron bihoreau (*Nycticorax nycticorax*) et 20 couples d'Aigrette garzette (*Egretta garzetta*). Ceci constitue la première citation de la reproduction de l'espèce en colonie à l'échelle du pays. Cette importante donnée représente l'extension au Maroc de la limite méridionale de la répartition de l'espèce à l'échelle du Paléarctique. Il faut noter que la Spatule blanche est une espèce menacée et en large déclin en Europe [<10.000 couples: France (5-7 couples), Italie (2-10 couples), Portugal (1-5 couples), Espagne (675 couples)].

4. **Plage sableuse:** Important biotope pour la reproduction du Gravelot à collier interrompu (plusieurs dizaines de couples) et de l'Oedicnème criard.

5. **Sansouire:** Cet habitat à *Salicornia* et *Sarcocornia* constitue un lieu de choix pour plusieurs populations d'oiseaux d'eau notamment le Gravelot à collier interrompu, l'Echasse blanche, le Canard colvert.

CHAPTER 3

TECHNIQUES FOR THE ECOLOGICAL CHARACTERIZATION OF SITES AND ECO-AUDITS:

Estimating the state of coastal ecosystems how to measure diversity

INTRODUCTION

Felicita Scapini

Diversity occurs at various levels of biological complexity, ranging from genes, individuals, local populations, species, communities of species, to landscape. It is a value *per se*, representing both the heritage from past evolution and the assurance for sustainability in the future. An ecosystem is characterised by the interactions of its elements, both physical and biological, and the more elements contribute to its construction the more complicated and stable it is. There are limits to the resistance of an ecosystem to the loss of its elements, and to the possibility of recovery after degradation. Each species within an ecosystem has particular needs and interrelationships that constitute its ecological niche, and can only survive if these are maintained.

Notwithstanding the conceptual and interpretative issues considered above (1.3.2), estimates of diversity remain important tools for the assessment of the health and sustainability of beach ecosystems. Eco-audits involving such assessments may be used to monitor the effects of environmental changes on the ecosystem. Indicator species, easy to recognise and sensitive to changes within an ecosystem may be used to estimate ecosystem health, but eco-audits based on the presence or absence of such sensitive elements (search of indicator species) are not useful in assessing the resistance of the ecosystem to change itself.

For the purpose of eco-audit we propose:

a) a procedure, which has been used to measure diversity at chosen Mediterranean coastal sites within the MECO project, based on the study of arthropod communities (3.1);
b) bioassays based on measures of diversity at the individual (genetic, physiological and behavioural) level for early warning and evaluation of adaptability to change (3.2.5);
c) a method based on population dynamics studies to identify inter-site variation (3.2.6).

3.1 MEASURES OF BIODIVERSITY BASED ON ARTHROPOD COMMUNITIES

Isabella Colombini, Mario Fallaci and Lorenzo Chelazzi

3.1.1 *Rationale*

Species richness and diversity are commonly used for conservation purposes and to assess ecosystem fitness. Ecological studies concerning more "natural" areas (coastal environments, forests etc.) show that species diversity is strongly correlated with habitat diversity. Furthermore environmental heterogeneity in space and time is important for species diversity and is related to disturbance regimes. Homogeneous landscapes (pinewood plantation on dunes, agricultural systems) generally result in loss of habitat and as fragmentation increases patch size and isolation aggravate the effect of habitat loss. In the Mediterranean basin the historical load of human land use and occupation is perhaps the overriding ecological factor to be considered and is of paramount importance when interpreting structure, composition and functioning of any ecosystem. An essential tool for environmental management is represented by ecological inventories and arthropods are a major component in most ecosystems. The study of arthropod communities along beach-dune systems is fairly simple in its techniques and can be used to assess the health of the ecosystem.

3.1.2 *Sampling procedure*

Two or more replicate transects (generally sufficient in sandy beach environments) were placed perpendicularly to the shoreline. These consisted of pitfall traps made by plastic cups (20 cm high and 10 cm in diameter) pushed in the sand to their rim and connected with one another by fibreglass bands (10 cm in height and 5 m long) (Fig. 3.1.1A). This system intercepted crawling arthropods.

In sites where beach-dune systems were extremely wide continuous transects were replaced with tetra-directional pitfall cross traps (Fig. 3.1.1B) placed at equivalent distances from one another or according to vegetation cover and/or habitat changes.

In order to intercept flying animals associated with the vegetation hand nets (Fig. 3.1.2A) were used and a standard number of strokes (n=100) were applied. Captures with hand nets can be plant specific or according to the major plant associations. Within the project it was carried out mainly according to the different zones (vegetated supralittoral, foredune, backdune, retrodune) (Fig. 3.1.2B).

For comparison between localities it is important that the same sampling effort is carried out in each site: same period of trapping, same number of traps and transects.

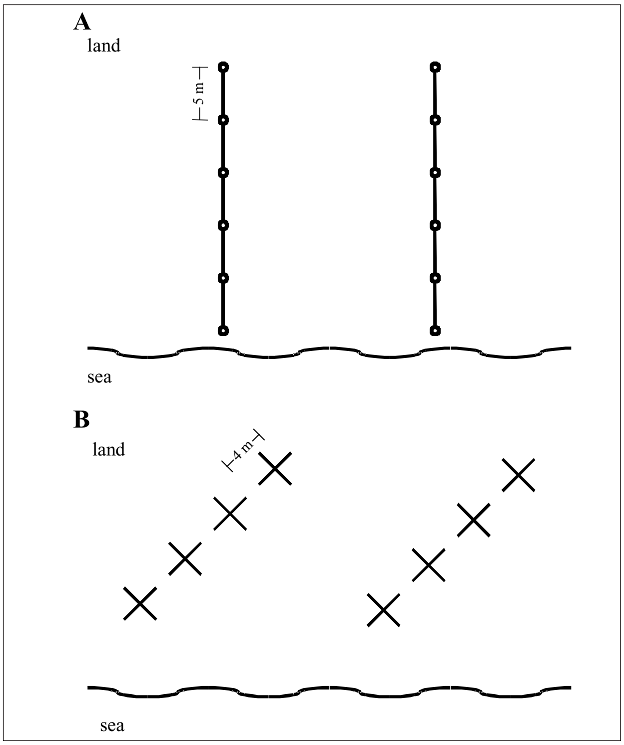

Fig. 3.1.1 (A) *Scheme of the trapping system used to intercept crawling arthropods on beaches. Circles indicate pitfall traps; lines, fibreglass bands.* (B) *Disposition of tetradirectional pitfall traps used on a wide beach*

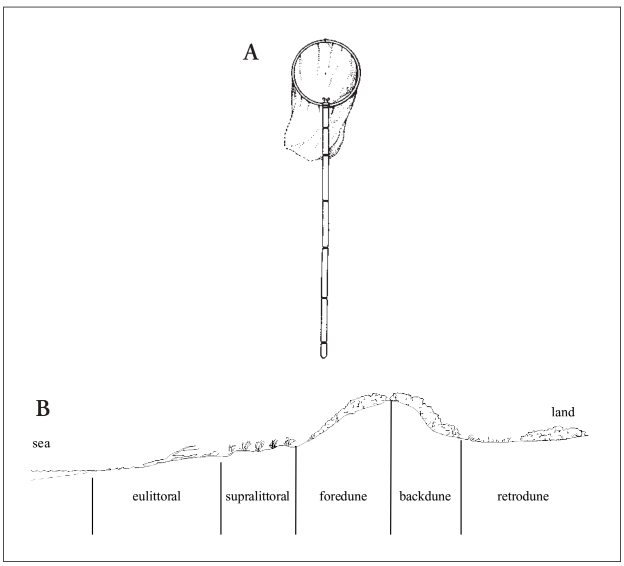

Fig. 3.1.2 (A) *Hand net used to intercept arthropods tied to the vegetation.* (B) *Zones of the beach-dune system: eulittoral, vegetated supralittoral, foredune, backdune, retrodune*

Transects were kept active 72 consecutive hours, during which recognisable taxa were counted. These animals were released at the end of the sampling period. All other samples were fixed in 75% alcohol and stored in the laboratory.

In the laboratory material was sorted under binocular microscopes and species were identified to order level.

The isopods and coleopterans alone (Harde, 1984) were chosen to be sorted further into morphologically recognisable taxonomic units (RTUs). Since determination at species level is extremely time consuming because often samples must be sent to specialists, this method permits to have an ideas of the number of species present in a sample, even if the name of the species is not given. This method consists in subdividing each order at family level and then in grouping the different species of each family with conventional names (sp.1, sp.2, sp.3,… etc.).

3.1.3 *Data analysis*

Ecological coefficients such as relative abundance may be used to provide an objective estimate of how the community is structured (Bigot and Bodot, 1973; Ponel, 1983). These involve estimating the abundance of individual species, as a function of

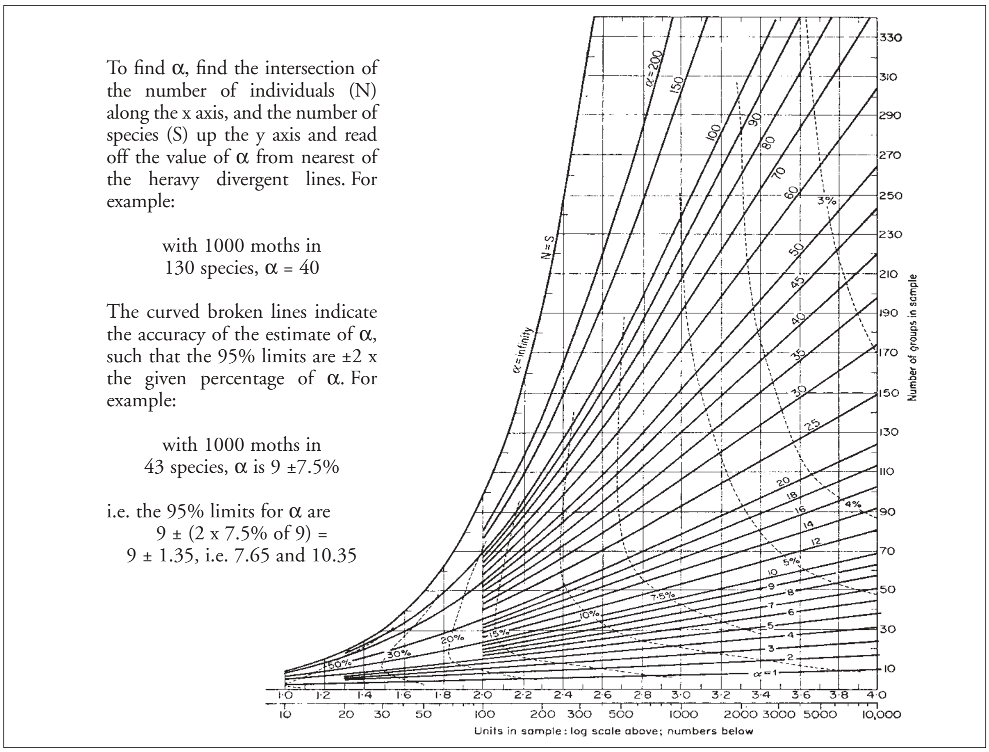

FIG. 3.1.3 *Williams' nomograph. The relation between total number of units, or individuals (N), the number of groups, or species (S), and the index of diversity (α) in the logarithmic series:* $S = \alpha \ln(1 - N/\alpha)$

the total number of individuals gathered in a particular zone or season. Species were then grouped as Abundant (A ≥ 5 %), Influent (2 ≤ A < 5 %) and Recedent (A< 2%).

Different indices provide different estimates of diversity, and have been used where appropriate. In a relatively large assemblage of individuals the frequency distribution of the number of species may be fitted to a logarithmic series (Fisher *et al.*, 1943). In the logarithmic series distribution the relation between the number of individuals and the number of species is given by:

$$S = \alpha \ ln(1+ N/\alpha)$$

where S is the number of species, N the number of individuals and α the diversity index. The diversity index α must be chosen to satisfy this above equation or it can be obtained from Williams' (1947) nomograph (Fig. 3.1.3). Confidence limits of α are calculated using the standard error given in Williams' nomograph.

The concept of evenness was introduced by Margalef (1958). The evenness of a community is high or low according as its several species are more or less evenly represented. To analyse the evenness Pielou's (1978) evenness index (J') was used:

$$J'=H'/H'max$$

where H' is the Shannon – Weaver (also called Shannon -Wiener) index (1949):

$$H'= -\sum p_i ln(p_i)$$

expressed in nats, when the base of the logarithm is 2 the unit is a bit, when it is 10, a decit and

$$H'max=ln(S)$$

where p_i is the proportion of the community that belongs to the *ith* species and S the number of species. The Shannon – Weaver index is used when it is assumed that the community is indefinitely large:

$$H'= -\sum p_i ln(p_i)$$

However for finite collections a more appropriate formula is that known as the Brillouin (1962) index (H) and is used instead of Shannon – Weaver index:

$$H=ln[N!/(N_1!N_2!...N_s!)]/N$$

where N is the number of individuals, N_1, N_2,...N_s are the individuals of the first, of the second.... and of the *sth* species, and

$$N!=N(N-1)(N-2)....2\cdot 1$$

In this case Pielou's (1978) evenness index (J) is:

$$J=H/Hmax$$

where *Hmax* is calculated dividing individuals among the species as evenly as possible, but when *N* is not a multiple of *S* the species cannot all have the same number of individuals. In this case, supposed *N=S[N/S]+r* where *[N/S]* is the integer part of the quotient *N/S* and *r* the remainder. Then *Hmax* is the diversity of a collection in which *S-r* species contain *[N/S]* individuals and the remaining *r* species contain *[N/S]+1* individuals.

Another diversity index is the Simpson's (1949) dominance index (*L*). This expresses the abundance of the commonest species as a fraction of the total number of individuals. This index decreases with increase in species number:

$$L = \sum n_i(n_i-1)/N(N-1)$$

where n_i is the number of individuals that belong to the *ith* species and *N* is the number of individuals of all species.

For a quantitative and qualitative analysis of the different zones, seasons and localities Renkonen's (1938) percentage similarity (*PS*) was computed. This compares the two samples in terms of individuals of the various species. It places the emphasis on the dominant species.

$$PS=2\sum min(p_{1i}, p_{2i})$$

where p_{1i}, and p_{2i} are the proportions of the *ith* species in the two compared samples and the summation is based on the minimum (*min*) of these two proportions.

The latter index allows computation of the changes in the community's composition along a sea-land gradient known as β-diversity (Whittaker 1972):

$$\beta = (lnPS_0-lnPS'n)/nln2$$

where PS_0 is the percentage similarity expected between two zones at zero distance from each other and *PS'n* is the percentage similarity of the total distance (*n*) between the first and last considered zone. The latter is calculated from the regression line obtained from each *PS* of the different zones.

3.1.4 *A case study-Results and interpretation*

In the MECO project diversity indexes were calculated for five different localities and were used to identify specie richness and habitat quality. The study was carried out both in the different zones on the beach dune system and on a seasonal basis. As an example the methods and results of the locality of Zouara (N 37° 0' 41", E 8° 53' 26", Tunisia, presented in sections 2.1 and 2.3) are here reported.

Standard samples using pitfall traps were taken along two transects from sea towards land. These traps captured arthropods spontaneously active at the sand surface. Traps were placed every five meters up to 40 m and from this point every two metres until the shoreline using a continuous fiberglas strips proceeding from the base of the dune towards sea (Fig. 3.1.1A). By contrast tetra-directional cross traps were placed at 20 m, 50 m, 90 m, 140 m from the base of the dune towards land (Fig. 3.1.1B). The transect was then divided in zones starting from the sealine limits: zone 1 (62-30 m calculated from the dune's base), zone 2 (25-0 m), zone 3 (20 m and 50 m from the base of the dune towards land), zone 4 (90 m and 140 m). Traps were active for 72 consecutive hours and were controlled periodically.

Abundance. The results of the abundance analysis calculated for the coleopterans and isopods during the two seasons are reported in Tables 3.1.1 and 3.1.2. For briefness only the total abundance is shown but calculations were made for each of the four zones. At Zouara a total number of 6148 of Coleoptera belonging to 63 species was collected. Of these 44 species were present in April and 34 in October. During April (Table 3.1.1) the most abundant coleopteran species was St5 (*Phytosus nigriventris*) with 64.338%. This species was followed by an anthicid of the *Anthicus* genus (An1, 10.163%), an histerid (Hi1 6.464%) and a tenebrionid (*Phaleria acuminata*) (Te29, 5.343%). In October the latter species becomes the most abundant (36.981%) followed by tenebrionids of the *Xanthomus* genus (Te15, 14.465%), a scarabeid (*Geotrupes stercorarius*) (Sc5, 11.572%), a carabid (*Eurynebria complanata*) (Ca28, 10.943%) and another tenebrionid (*Pseudoseriacius olivieri*) (Te40, 7.170%). In October St5 and An1 greatly decrease and become influent (3.774 and 2.642% respectively). Instead Hi1 was not collected in October. For the isopods a total number of 12440 individuals were sampled at Zouara (Table 3.1.2). These belonged to three species: *Armadillidium album*, *Porcellio lamellatus* and *Tylos europaeus.* In April all three species were collected whereas in October only two. In both seasons only *T. europaeus* was abundant with 99.905 % and 99.976 % in spring and autumn respectively.

Species diversity. Analysing the coleopteran community of the beach-dune system of Zouara with Fisher's diversity index, the α coefficient found for October was higher than that of April (7.22 and 6.56 respectively) (Table 3.1.3A). Considering the single zones individually the highest diversity values were obtained in zone 4 in April and in zone 1 in October (although in this season a similar value was also found in zone 4). Altogether the dune presented a higher diversity than that of the beach (10.38 and 5.90). In particular the highest values of α of the dune were obtained in April (8.50) whereas the lowest were found for the beach during the same period (3.31). On the whole Zouara presented an α diversity of 9.77. Similar analysis of the isopod community showed a higher α coefficient in April (0.32) with respect to October (0.19) (Table 3.1.3B). Considering the zones individually it was zone 3 that presented the highest values in both seasons (0.53 in April; 0.56 in October). The beach presented a very low value (0.08) compared to the dune (0.92) and this was higher in April (1.59). On the whole the isopod community presented a quite low α value (0.28) for the entire beach-dune system.

Evenness of the community. The index of evenness, estimated for the coleopterans over the entire beach-dune system by means of the Pielou-Brillouin

TAB. 3.1.1 *Abundance analysis of the Coleoptera family found at Zouara in all zones during the two seasons*

APRIL				OCTOBER			
Abundant	Staphylinidae	St 5	64.338	***Abundant***	Tenebrionidae	Te 29	36.981
	Anthicidae	An 1	10.163		Tenebrionidae	Te 15	14.465
	Histeridae	Hi 1	6.464		Scarabeidae	Sc 5	11.572
	Tenebrionidae	Te 29	5.343		Carabidae	Ca 28	10.943
					Tenebrionidae	Te 40	7.170
Influent	Staphylinidae	St 25	3.643	***Influent***	Staphylinidae	St 25	4.403
	Tenebrionidae	Te 5	2.597		Staphylinidae	St 5	3.774
	Carabidae	Ca 28	2.354		Anthicidae	An 1	2.640
Recedent	Tenebrionidae	Te 8	1.027	***Recedent***	Tenebrionidae	Te 4	1.258
	Tenebrionidae	Te 14	0.785		Scarabaeidae	Sc 8	1.006
	Scarabeidae	Sc 7	0.448		Tenebrionidae	Te 27	"
	Carabidae	Ca 37	0.336		Staphylinidae	St 10	0.629
	Carabidae	Ca 36	0.318		Tenebrionidae	Te 22	0.503
	Scarabeidae	Sc 5	"		Tenebrionidae	Te 26	"
	Tenebrionidae	Te 26	"		Carabidae	Ca 10	0.377
	Tenebrionidae	Te 9	0.205		Tenebrionidae	Te 28	"
	Tenebrionidae	Te 1	0.168		Carabidae	Ca 37	0.252
	Tenebrionidae	Te 25	0.149		Anobiidae	A 1	0.126
	Staphylinidae	St 27	0.131		Carabidae	Ca 11	"
	Cryptophagidae	Cr 1	0.093		Carabidae	Ca 17	"
	Tenebrionidae	Te 13	"		Carabidae	Ca 21	"
	Curculionidae	Cur 30	0.075		Carabidae	Ca 25	"
	Staphylinidae	St 10	"		Carabidae	Ca 32	"
	Curculionidae	Cur 29	0.056		Chrysomelidae	Ch 9	"
	Ptiliidae	Pt 4	"		Cicindelidae	Ci 1	"
	Cerambicidae	Ce 3	0.037		Cicindelidae	Ci 2	"
	Coccinellidae	Co 1	"		Cicindelidae	Ci 3	"
	Hydrophilidae	Hyd 1	"		Coccinellidae	Co 2	"
	Staphylinidae	St 26	"		Curculionidae	Cur 15	"
	Anthicidae	An 5	0.019		Curculionidae	Cur 26	"
	Cantaridae	C 1	"		Staphylinidae	St 7	"
	Carabidae	Ca 11	"		Tenebrionidae	Te 13	"
	Carabidae	Ca 16	"		Tenebrionidae	Te 17	"
	Carabidae	Ca 31	"		Tenebrionidae	Te 24	"
	Carabidae	Ca 35	"				
	Cerambicidae	Ce 2	"				
	Cicindelidae	Ci 1	"				
	Cucujidae	Cu 3	"				
	Curculionidae	Cur 26	"				
	Elateridae	El 1	"				
	Elateridae	El 2	"				
	Hydralnidae	Hy 3	"				
	Scarabeidae	Sc 1	"				
	Scarabeidae	Sc 4	"				
	Tenebrionidae	Te 15	"				

TAB. 3.1.2 *Abundance analysis of the Isopoda found at Zouara in all zones during the two seasons*

APRIL				OCTOBER			
Abundant	Tylidae	*Tylos europaeus*	99.905	***Abundant***	Tylidae	*Tylos europaeus*	99.976
Recedent	Porcellionidae	*Porcellio lamellatus*	0.071	***Recedent***	Porcellionidae	*Porcellio lamellatus*	0.024
	Armadillididae	*Armadillidium album*					

method, was 0.422 (Table 3.1.3A). This value was higher in October (0.599) than in April (0.381). In the latter season the highest value was obtained in zone 4 (0.686), the lowest in zone 1 (0.233). In October it is zone 3 (0.821), in which the coleopteran community are most evenly distributed. Considering the beach and the dune separately the highest uniformity between species was found on the dune. In contrast the equivalent value for evenness of isopod distribution over the same beach dune system was extremely low (0.004) when estimated with this method (Table 3.1.3B). This value was 0.007 in April and 0.002 in October. On the dune the value of Pielou-Brillouin index was 0.609, whereas on the beach it was not calculated being present only one species. In particular, the highest value was found on the dune in April (0.774).

Species dominance. Simpson's dominance index calculated for the coleopterans at Zouara was 0.344 (Table 3.1.3A) and more dominant species were found in April (0.434) than in October (0.192). In both seasons the highest values were obtained in zone 1 and this was due to the presence on the beach of a great number of Staphylinidae (*Phytosus nigriventris*) and of Tenebrionidae (*Phaleria acuminata*) respectively in spring (0.540) and autumn (0.364) months. The higher dominance indices on the beach (0.458) than on the dune (0.107) may also be attributed to these species. For the isopods, Simpson's dominance index for the entire system was 0.999. This reached it's maximum value (1.000) in October, and it is slightly lower in April (0.998). In general the dominance index reached it's highest value on the beach where only *Tylos europaeus* was present in great quantity. On the dune the value decreases to one half of it, due to the presence of also other isopod species.

TAB. 3.1.3 *Ecological indices of the Coleoptera (A) and Isopoda (B)*

A	APRIL ZONE 1	APRIL ZONE 2	APRIL ZONE 3	APRIL ZONE 4	OCTOBER ZONE 1	OCTOBER ZONE 2	OCTOBER ZONE 3	OCTOBER ZONE 4	APRIL BEACH	APRIL DUNE	OCTOBER BEACH	OCTOBER DUNE	BEACH	DUNE	APRIL	OCTOBER	TOTAL
n	3079	1622	323	329	274	222	102	197	4701	652	496	299	5197	951	5353	795	6148
n species	18	20	25	28	20	15	13	16	24	37	25	20	40	47	44	34	63
Fisher et al.	2.53	3.21	6.33	7.31	4.96	3.63	3.95	4.11	3.31	8.50	5.55	4.83	5.90	10.38	6.56	7.22	9.77
Fisher's conf. cim.	0.48	0.62	1.47	1.65	1.29	1.07	1.47	1.19	0.50	1.50	1.19	1.38	0.74	1.54	0.76	1.26	0.94
Shannon	0.680	1.605	2.088	2.290	1.198	1.682	2.110	1.949	1.120	2.282	1.527	2.143	1.330	2.613	1.448	2.118	1.753
Brillouin	0.669	1.582	1.975	2.168	1.112	1.587	1.925	1.828	1.110	2.196	1.459	2.037	1.317	2.534	1.434	2.052	1.735
Shannon max	2.890	2.996	3.219	3.332	2.996	2.708	2.565	2.773	3.178	3.611	3.219	2.996	3.689	3.850	3.784	3.526	4.143
Brillouin max	2.872	2.960	3.060	3.159	2.846	2.570	2.346	2.613	3.161	3.483	3.105	2.856	3.664	3.735	3.758	3.425	4.111
Pielou-Shannon	0.235	0.536	0.649	0.687	0.400	0.621	0.823	0.703	0.352	0.632	0.475	0.715	0.361	0.679	0.383	0.601	0.423
Pielou-Brillouin	0.233	0.534	0.646	0.686	0.391	0.617	0.821	0.699	0.351	0.631	0.470	0.713	0.360	0.679	0.381	0.599	0.422
Simpson	0.732	0.300	0.186	0.139	0.473	0.271	0.145	0.192	0.540	0.153	0.364	0.160	0.458	0.107	0.434	0.192	0.344

B	APRIL ZONE 1	APRIL ZONE 2	APRIL ZONE 3	APRIL ZONE 4	OCTOBER ZONE 1	OCTOBER ZONE 2	OCTOBER ZONE 3	OCTOBER ZONE 4	APRIL BEACH	APRIL DUNE	OCTOBER BEACH	OCTOBER DUNE	BEACH	DUNE	APRIL	OCTOBER	TOTAL
n	3823	395	3	1	5749	2450	19	-	4218	4	8199	19	12417	23	4222	8218	12440
n species	1	1	1	1	1	1	2	-	1	2	1	2	1	3	3	2	3
Fisher et al.	0.09	0.12	0.53		0.09	0.10	0.56		0.09	1.59	0.09	0.56	0.08	0.92	0.32	0.19	0.28
Fisher's conf. lim.	-	-	-	-	-	-	0.50	-	-	-	-	0.50	-	0.71	-	-	-
Shannon	-	-	-	-	-	-	0.336	-	-	0.562	-	0.336	-	0.692	0.008	0.002	0.004
Brillouin	-	-	-	-	-	-	0.271	-	-	0.347	-	0.271	-	0.579	0.007	0.002	0.004
Shannon max	-	-	-	-	-	-	0.693	-	-	0.693	-	0.693	-	1.099	1.099	0.693	1.099
Brillouin max	-	-	-	-	-	-	0.602	-	-	0.448	-	0.602	-	0.951	1.097	0.693	1.098
Pielou-Shannon	-	-	-	-	-	-	0.485	-	-	0.811	-	0.485	-	0.629	0.007	0.003	0.004
Pielou-Brillouin	-	-	-	-	-	-	0.450	-	-	0.774	-	0.450	-	0.609	0.007	0.003	0.004
Simpson	1	1	1	-	1	1	0.801	-	1	0.5	1	0.801	1	0.577	0.998	1	0.999

Similarity of the communities. The community of coleopterans collected at Zouara was compared with Renkonen's (1938) percentage similarity in the two seasons and with the coleopterans found in other localities (Smir, Morocco, Ir-Ramla tat-Torri, Malta, Ir-Ramla l-Hamra, Gozo) (Fig. 3.1.4 A, B). At Zouara in the two seasons the percentage of similarity for coleopterans was not particularly high (16.7%). The highest percentage of similarity was obtained between Smir in spring and Zouara in autumn (43.1%) whereas the lowest between Zouara in spring and Ir-Ramla tat-Torri in autumn (0.8%). On the total (Fig. 3.1.4 B) the localities that presented the most similar coleopteran fauna are Smir and Ir-Ramla tat-Torri with percentage of similarity of 23.9%. The lowest similarity was instead found between Zouara and Ir-Ramla tat-Torri (8.1%). For the isopods (Fig. 3.1.4C) the highest percentage of similarity was found between Smir in autumn and Zouara in spring

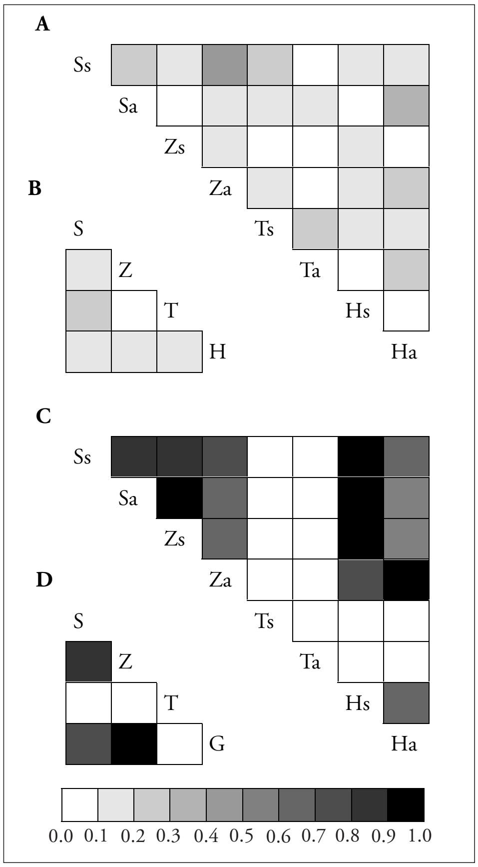

FIG. 3.1.4 *Renkonen's percentage of similarity, between the different localities, for the coleopterans in the two seasons* (**A**) *and in the total* (**B**) *and for the isopods in the two seasons* (**C**) *and in the total* (**D**). *(Ss= Smir in spring; Sa= Smir in autumn; Zs= Zouara in spring; Za= Zouara in autumn; Ts= Ir-Ramla tat-Torri in spring; Ta= Ir-Ramla tat-Torri in autumn; Hs= Ir-Ramla l-Hamra in spring; Ha= Ir-Ramla l-Hamra in autumn; S= Smir; Z= Zouara; T= Ir-Ramla tat-Torri; H= Ir-Ramla l-Hamra)*

(96.3%). High similarities were also found when the isopod fauna of Ir-Ramla l-Hamra of spring was compared with that of Smir in both seasons and with Zouara in spring. Furthermore the isopod fauna of Ir-Ramlal-Hamra of autumn was similar to that of Zouara in autumn. On the total (Fig. 3.1.4 D) the localities that presented the most similar isopod fauna were Zouara and Ir-Ramla l-Hamra with a percentage of similarity of 91.9%. High similarities were also found between Smir and Zouara and between Smir and Ir-Ramla l-Hamra. Ir-Ramla tat-Torri differed the most in its isopod fauna when compared with the other study localities.

The results indicate that Zouara locality (Tunisia) presented a faunal community with a diversity similar to other localities (Smir, Morocco; Ir-Ramla tat-Torri, Malta; Ir-Ramla l-Hamra, Gozo) studied along the Mediterranean. The number of species present in the beach-dune system was quite high and there was an increase of species from the beach towards the dune. The system presented few dominant species that changed both in quantity and in quality according to the season. For coleopterans, specie's uniformity reached higher values in autumn months as the number of dominant species tended to decrease in this season. Isopods, mainly represented by only one species typical of the beach, were quite consistent showing a good quality of the beach habitat.

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3.2 BIOASSAYS FOR ESTIMATION OF BEACH STABILITY AND ECOSYSTEM QUALITY

Felicita Scapini and Elfed Morgan

The quality of beach ecosystems generally depends on the shoreline stability, and healthy ecosystems in turn contribute to shoreline stability, as they allow for natural equilibrium. Human intervention, management, and other changes may upset the balance of this equilibrium. Bioassays of key species allow rapid estimation of such changes and are proposed for regular monitoring of beaches with a view to sustainable management.

The basic requirements for a suitable bioassay are: 1) availability of the biological material; 2) availability of the necessary equipment; 3) ease of execution by one/two persons after short training; 4) clear interpretation that follows from previous testing and comparison with existing baseline data; 5) reliability with which the biological parameter can be repeatedly measured.

The bioassays proposed here have been developed and tested in real cases within the MECO project. Details are presented concerning points 1, 2 and 3, as well as examples of how the bioassays were applied, and the relevant bibliography is given, to meet requirements 4 and 5.

Key species are elements of the ecosystem playing a relevant role for its equilibrium, and are thus important indicators of sustainability for management purposes. Any change of a key species would affect the ecosystem and conversely changing ecosystems would cause changes in the key species. In principle, any species of a healthy ecosystem could be considered a key species, as it interacts with other elements of the ecosystem. However, not all species are of equal importance. This is particularly true for ecosystems like beaches where biological links are generally less important than physical constraints. The choice of the key species is an important step in the development of a bioassay. First of all, its role within the ecosystem should be clearly recognised. Burrowing animals favour sediment turn over, and colonising plants contribute to dune fixation, for example. Some of the common arthropod species dwelling in sand beaches are good candidates for bioassays (Fig. 3.2.1).

To meet requirement 1) above, a key species should be easy to find, recognise and sample. We have chosen an animal, *Talitrus saltator* (Fig. 3.2.2), and a plant, *Cakile maritima* (Fig. 3.2.3), colonising the beach and fore dune respectively. These are the zone of a beach most used for leisure, and are also very important for sediment equilibrium (turn over, transport and fixation) and consequently shoreline stability.

T. saltator and *C. maritima* show a number of characteristics which make them appropriate for bioassays.

1. Both have a widespread distribution. *T. saltator* has spread from the Mediterranean and has colonised European coasts of the Atlantic to the southern Baltic. This distribution makes the species suitable for comparative analysis, as it is found on sand coasts subject to different environmental conditions: latitudinal, climatic, tidal, erosion/accretion, subject/non subject to human impacts. *C. maritima* is similarly widely distributed, contributing to dune stabilisation on most Mediterranean beaches, and is also a common member of the sand dune flora on the Atlantic shores of Europe.
2. They are located in the beach zones that are most likely to be affected by leisure activities, *T. saltator* burrows in the sand at the edge of the tide, and *C. maritima* grows on the fore dune.
3. They are locally abundant, thus permitting easy sampling without endangering the ecosystem. In particular, *C. maritima* forms many, easily recognisable individuals, derived from different seeds, and it is possible to sample only small parts of each plant, leaving the plant alive in its natural location.
4. Both have relatively short life cycles. Thus all the life stages of *T. saltator* are available for bioassays, while the annual cycle of *C. maritima* allows different parts of the plant, leaves, flowers, and fruits to be sampled during this period.
5. In addition, *T. saltator* is relatively robust and recorded also in beach ecosystems under threat, polluted or eroded. For this reason it can not be considered an indicator species of impact for its presence/absence, but differences between local populations reflect differences between beaches, so that it is suitable for monitoring

Fig. 3.2.1 *Examples of common arthropod species of sand beaches, candidates as key species for bioassays to assess the health of beach ecosystems. On the left three crustaceans are shown, the isopod* Tylos europaeus *and the amphipods* Talitrus saltator *and* Talorchestia brito*; on the right the coleopterans* Eurynebria complanata*,* Scarites laevigatus *and* Phaleria acuminata

ecosystem adaptability or adaptation to changes. In this context, the ease with which it can be kept and reared in the laboratory is important, permitting in-depth physiological and genetic studies.

FIG 3.2.2 *Photograph of a live adult male* Talitrus saltator*, of body length about 2 cm. Key for the identification of the species recommended (Ruffo, The Amphipoda of the Mediterranean – Part III, Memoires de l'Institut Oceanografique, Monaco, 13, 1993)*

FIG. 3.2.3 *Photograph of a flowering* Cakile maritima *plant. The leaves only were used for the DNA analyses*

3.3 GENETIC INDICATORS

3.3.1 *Variation in isoenzymes – Protein electrophoresis*
(Valerio Ketmaier and Elvira De Matthaeis)

a. *Principles*

The issue of bio-diversity can be approached at various levels of organisation, the most basic been **genetic diversity** which encompasses the variation in the genetic make-up among individuals both within a population and between populations. The analysis of the genetic structure of natural populations has become a central task in evolutionary studies.

There exists a wide variety of laboratory assays for revealing molecular genetic markers to detect genetic variation in natural populations. Protein electrophoresis, the migration of proteins under the influence of an electric field, is among the most cost-effective methods for investigating genetic phenomena at the molecular level. Since their first appearance, allozyme studies determined a major revolution in understanding micro- and macroevolutionary processes. Today there are several methods that allow direct analysis of DNA sequences, but the frequency of allozyme-based investigations has not waned in recent years. On the contrary the application of such studies has increased, as refinements and new methods have been developed. In particular, in Table 3.3.1 are shown levels of evolutionary divergence at which allozymes and DNA sequencing provide informative markers. Allozymes are highly informative and appropriate markers for studies from the level of conspecific populations to the closely related species level, whereas DNA sequencing is well fitted for intermediate taxonomic levels and deeper separation (>50 mya).

TAB. 3.3.1 *Levels of evolutionary divergence at which allozymes and DNA sequencing normally provide informative markers (modified from Avise, 1994)*

HIERARCHICAL LEVEL	PROTEIN ELECTROPHORESIS	DNA SEQUENCING
Conspecific populations	**	*
Closely related species	**	*
Intermediate taxonomic level	*	**
Deep separation (> 50 mya)	-	**

(**)-highly informative; (*)-marginally informative; but not an ideal approach for reasons of cost-ineffectiveness or other difficulties; (-)-inappropriate use of method.

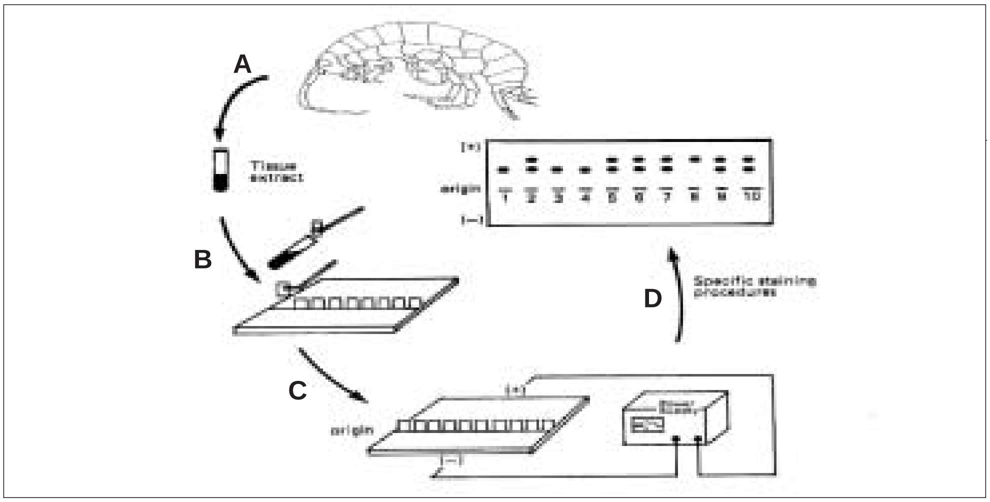

FIG. 3.3.1 *Scheme of starch gel electrophoresis.* (**A**) *Tissue homogenization to extract enzymatic proteins;* (**B**) *Gel loading with wicks of filter paper wetted with tissue extracts;* (**C**) *Application of electrical current to separate proteins;* (**D**) *Visualisation of protein bands on the gel by specific histochemical staining*

b. *Procedures: electrophoretic analysis*

The basic outline of starch gel electrophoresis is shown in Fig.3.3.1. Hydrolysed starch is heated in an ionic solution and allowed to cool, forming a gel. Electrical current separating protein solutions is applied to the gel via the ionic buffers. Following electrophoresis the proteins may be visualised as bands on the gel by specific histochemical staining. Protein electrophoresis is used to illustrate the changes in the amino acid sequences in the encoding DNA locus due to mutations, that may affect the net charge of the protein itself. The banding pattern of an individual contains information on the individual's genotype at a number of structural loci.

c. *Data analysis*

Raw electrophoretic data (*i.e.* number of different scored genotypes at single study loci) have to be processed to quantify the amount of genetic variation and differentiation of the study populations.

Genetic variability of study populations, estimated as heterozygosity per locus is given by:

$$H_L = 1 - \Sigma x_i^2$$

where x_i is the frequency of the *ith* allele at a locus, which is given by:

$$x_i = 2H_o + H_e / 2N$$

where H_o is the number of homozygotes for that allele, H_e is the number of heterozygotes for that allele and N is the number of individuals examined. Mean heterozygosity per population is calculated as the proportion of individuals sampled that are heterozygous (direct-count) and the unbiased estimated (Nei, 1978), based on

Hardy-Weinberg expectations. Other measures of genetic variability are the mean number of alleles per locus and the percentage of loci polymorphic. A locus has been considered polymorphic if the frequency of the most common allele does not exceed 0.99.

Several measures are available to quantify the genetic differentiation between populations. The most widely used statistics are those of Nei (1978). Nei's coefficient of genetic identity (I) between two taxa is given by:

$$I=\Sigma x_i y_i/\sqrt{(\Sigma x_i^2 \Sigma y_i^2)}$$

where x_i and y_i are the frequencies of the *ith* allele in populations X and Y respectively. I=1 when X and Y are monomorphic for the same allele and I=0 when X and Y are monomorphic for different alleles. The mean genetic identity (I_{mean}) is the mean over all loci studied and is given by:

$$I_{mean}=I_{XY}/\sqrt{(I_X I_Y)}$$

where I_{XY}, I_X and I_Y are the arithmetic means, over all loci of $\Sigma x_i y_i$, Σx_i^2 and Σy_i^2 respectively.

The genetic distance (D) is estimated by:

$$D=-lnI$$

When genetic identity and/or distance have been calculated for all possible pairs of populations, results can be presented as dendrograms. Various methods are available for dendrogram construction. In this work we have applied to the genetic distance values (D; Nei, 1978) the unweighted pair-group arithmetic average (UPGMA) clustering method, which performs hierarchical cluster analysis starting from the two populations with the lowest genetic distance between them.

d. *A case study*

In this section we intend to show, through a case study on amphipods, the basic principles and interpretation of data yielded by protein electrophoresis. Detailed laboratory protocols can be found in Murphy *et al.* (1996).

Pattern of genetic divergence and variability in Mediterranean talitrids (Crustacea, Amphipoda) based on allozyme data

Introduction

Two of the major applications of protein electrophoretic deal with the recognition of species and their evolutionary relationships (molecular systematics) and estimating and understanding genetic variability in natural populations.

For several years we have had ongoing projects on the study of the genetic variation among populations of *Talitrus saltator* (Amphipoda, Talitridae). Up to date we have a quite deep knowledge of the pattern of genetic structuring of this species at the scale of the whole Mediterranean (De Matthaeis *et al.*, 1994; 1995; 1998; 2000a). The main results of these studies have been the identification of geographic groups, highly genetically divergent from each other. In particular a mean degree of genetic distance (D; Nei, 1978) of 0.4 was found among Tyrrhenian, Adriatic and Aegean populations of this species (Fig.3.3.2). D values of the same order of magnitude are frequently reported for interspecific comparisons (Thorpe, 1983; Stewart, 1993). The outcome of these evidences may so be used as a frame to place the analysis of the genetic structure of the *T. saltator* populations from North African coasts. Here we report data on the genetic structure on three North African populations of *T. saltator*, one from Morocco and two from Tunisia. We have compared these populations with several other populations, which could be considered representative of the above-mentioned geographic groups, in order to understand the pattern of genetic relationships of these newly studied populations with the other geographic groups of *T. saltator*. *T. saltator* may be frequently found associated with species belonging to the genus *Talorchestia* such as *T. deshayesii* and *T. brito*. In particular, at Tabarka beach (Tunisia) we found both *Talitrus saltator* and *Talorchestia brito*, whereas at Zouara (Tunisia) *T. brito* was the most abundant species. Within *Talorchestia deshayesii*, available genetic data (De Matthaeis *et al.*, 1994) indicate a less pronounced degree of genetic differentiation among Italian populations than in *Talitrus saltator*. However, more recently, De Matthaeis *et al.* (2000b) pointed out the considerable amount of genetic differentiation of a population of *Talorchestia deshayesii* from Ramla Bay (Ramla l-Hamra, Gozo, described in section 2.4) with respect to several other conspecific populations (D_{mean}= 0.260) (Fig. 3.3.3). Ramla Bay is a sandy beach of extreme ecological value but highly impacted during the tourist season.

Moreover, because *Talitrus saltator* is a typical element of the supralittoral fauna it can be considered a good candidate as source of biological information in order to yield important results on the quality of the study coastal sites. The rationale for this approach comes from several experimental studies that have shown a non-random association between levels of genetic variability and temporal and spatial patterns of environmental variations (Ayala *et al.*, 1975; Scapini *et al.*, 1995). Environmental stress, natural or anthropogenic, may cause variations in the genetic structure of natural populations (Hummel and Patarnello, 1994). Korol *et al.* (1996) have demonstrated mathematically that cyclical changes of the environmental optimum cannot help in polymorphism maintenance. Under these assumptions, several efforts have been made to use genetic markers as possible tools in analysing the impact of human-induced alterations on the quality of certain environments (Nevo *et al.*, 1984; Foré *et al.*, 1995a). We intend to highlight the predictive potential of both supralittoral amphipods and this class of molecular markers in evaluating the state of health of different coastal ecosystems.

Material and methods

Sampling

The study populations, identified by a three-letter code, are listed in Table 3.3.2 and the geographic locations of sampling sites are shown in Fig. 3.3.4.

Electrophoresis

In the present work we have used 12 enzymatic proteins to assess the degree of genetic polymorphism of the study populations. In Table 3.3.3 are listed the

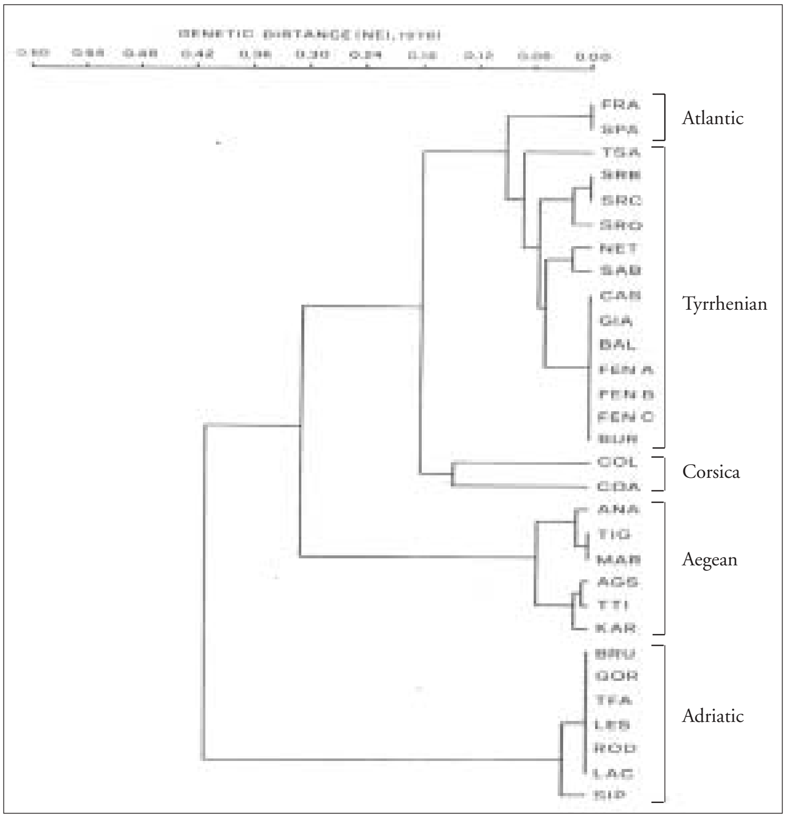

FIG. 3.3.2 *UPGMA dendrogram showing the mean genetic distances among* Talitrus saltator *populations from Atlantic, Tyrrhenian, Adriatic and Aegean coasts*

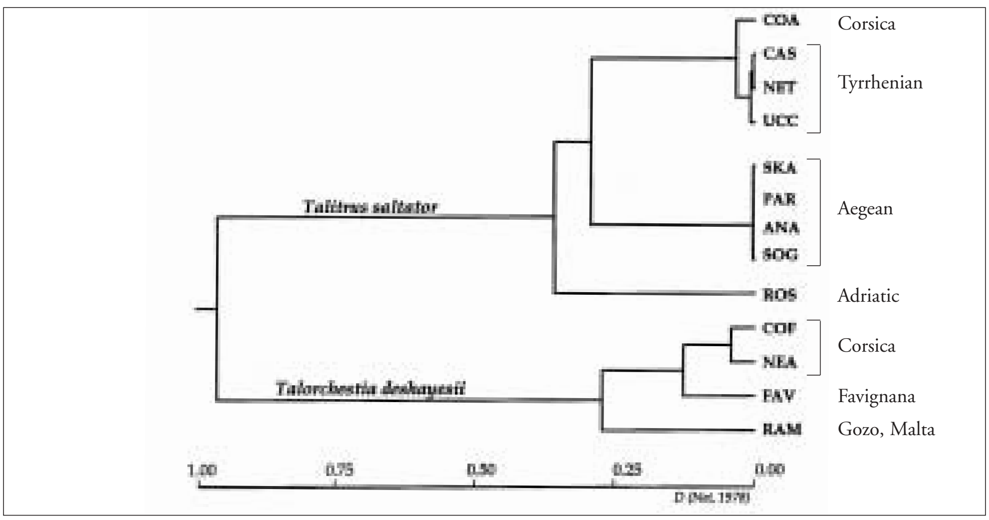

FIG. 3.3.3 *UPGMA dendrogram showing the genetic differentiation between* Talitrus saltator *and* Talorchestia deshayesii *from Mediterranean coasts*

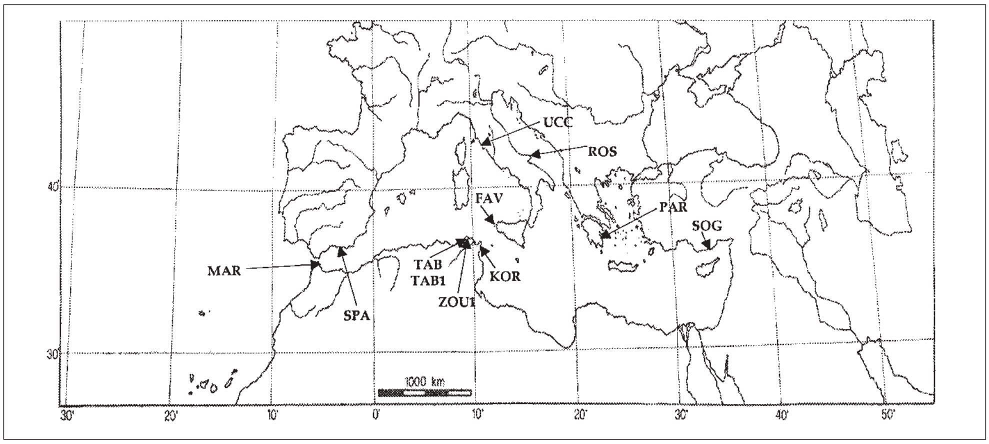

Fig. 3.3.4 *Sampling localities of study populations*

Tab. 3.3.2 *Geographic locations and codes of the study populations and species*

SPECIES	LOCALITY	CODE
Talitrus saltator		
	Italy: Tuscany, Parco dell'Uccellina	UCC
	Italy: Apulia, Rodi Garganico	ROS
	Greece: Peloponnesus, Paralio Astros	PAR
	Turkey: Anatolia, Soguksu	SOG
	Tunisia: Korba	KOR
	Tunisia: Tabarka	TAB
	Morocco: Kabyla beach	MAR
Talorchestia deshayesii		
	Spain: Almeria	SPA
	Italy: Favignana, porto	FAV
Talorchestia brito		
	Tunisia: Tabarka	TAB1
	Tunisia: Zouara	ZOU1

Tab. 3.3.3 *Enzymes tested, E.C. numbers, buffer systems, staining techniques and scored loci. For Buffer systems and Staining techniques see De Matthaeis et al. (1994; 1995; 1998)*

CODE	ENZYME	E.C.N°.	BUFFER SYSTEMS	STAINING TECHNIQUES	SCORED LOCI
Acph	Acid phosphatase	3.1.3.2	A	Tracey et al., 1975	*Acph1; Acph2; Acph-3*
Ao	Aldehyde oxidase	1.2.3.1	B	Ayala et al., 1974	*Ao*
Aph	Alkaline phosphatase	3.1.3.1	A	Ayala et al., 1972	*Aph1; Aph2*
Ca	Carbonic anhydrase	4.2.1.1	G	Brewer & Sing, 1970	*Ca1; Ca2*
Est	Esterase	3.1.1.1	A	Ayala et al., 1972	*Est2; Est3*
Got	Glutamic-oxalacetic transaminase	2.6.1.1	B[1]	Ayala et al., 1975	*Got1; Got2*
Hk	Exokinase	2.7.1.1	C	Ayala et al., 1974	*Hk*
Lap	Leucine-amino peptidase	3.4.11.1	A	Ayala et al., 1972	*Lap1; Lap2*
Mpi	Mannose phosphate isomerase	5.3.1.8	I	Harris & Hopkinson, 1978	*Mpi*
Pep	Peptidase	3.4.11	A	Shaw & Prasad, 1970	*Pep1; Pep2; Pep3*
Pgm	Phosphoglucomutase	2.7.5.1	D	Brewer & Sing, 1970	*Pgm*
Phi	Phosphoexose isomerase	5.3.1.9	C	Brewer & Sing, 1970	*Phi*

study proteins, buffer systems, stains and the number of scored loci. Data have been analysed according to the *Data analysis* section (see above). The program Biosys-1 (Swofford and Selander, 1981) has been used to carry out all the data analyses.

Results and Discussion

Twenty-one presumptive gene loci from 12 enzyme systems were scorable in all populations. Electromorphs of *Pep-1* and *Pep-2* were monomorphic and fixed for the same allele in all population samples.

Genetic variation within *Talitrus saltator*

The *Ca-2* and *Got-2* loci were found to be diagnostic for the North-African populations from all other geographic groups of *T. saltator* (Table 3.3.4). The *Ca-2 B* and *Got-2 B* alleles completely discriminated the North-African group of populations from the Tyrrhenian, Adriatic and Aegean populations. Moreover we found the *Ao* locus to be diagnostic for the MAR population. We found one private allele in the KOR population: the *Aph-2 B* allele was found in the KOR population only.

The genetic distances (*D*) between populations are shown in Table 3.3.5. The values of *D* within the North-African group varied from 0.040 (TAB-KOR) to 0.102 (TAB-MAR). The three North-African populations were quite distant from each Tyrrhenian, Adriatic and Aegean populations with an average value of $D = 0.270$. The intergroup values of *D* were quite different: *D* varied from 0.271 (UCC-TAB) to 0.519 (ROS-TAB).

TAB. 3.3.4 *Diagnostic loci among geographical groups of* Talitrus saltator

GEOGRAPHICAL GROUPS	T	A	EM	NA
T	-			
A	*Acph3; Ao1; Ca2; Est1; Est2*	-		
EM	*Acph3; Ca1; Got1*	*Acph3; Ao1; Ca1; Got1*	-	
NA	*Ca2; Got2*	*Ca2; Got2*	*Ca2; Got2*	-

T= Tyrrhenian group
A= Adriatic group
EM= East-Mediterranean group
NA= North-African group

Genetic variation within *Talorchestia deshayesii*

The two populations of the species were added to the present study in order to easily discriminate individuals belonging to different species. Usually taxonomists utilise morphological characters to separate species but it must be remembered that when dealing with talitrid specimens it is difficult to discriminate in the field juveniles and females belonging to *Talitrus* and *Talorchestia*. The allozymes can be utilised as diagnostic characters. In the North-African samples we did not find any individual belonging to *Talorchestia deshayesii*.

TAB. 3.3.5 *Genetic distance values (D, Nei, 1978) among study populations and species*

Pop.	SOG	PAR	ROS	UCC	TAB	KOR	MAR	TAB1	ZOU1	FAV	SPA
SOG	*****										
PAR	0.052	*****									
ROS	0.355	0.367	*****								
UCC	0.299	0.364	0.389	*****							
TAB	0.346	0.411	0.519	0.271	*****						
KOR	0.313	0.377	0.484	0.229	0.040	*****					
MAR	0.335	0.404	0.464	0.321	0.102	0.061	*****				
TAB1	1.426	1.658	1.916	1.332	1.425	1.381	1.596	*****			
ZOU1	1.410	1.642	1.899	1.316	1.408	1.364	1.579	0.007	*****		
FAV	0.638	0.647	0.841	0.715	0.559	0.627	0.618	1.658	1.642	*****	
SPA	0.643	0.652	0.847	0.714	0.562	0.630	0.624	1.652	1.636	0.000	*****

Genetic variation within *Talorchestia brito*

The two populations of the species resulted to be genetically similar. At the *Mpi* locus only, the two populations differed in the frequency of the most common allele: the allele F was fixed in the TAB1 population, while two more alleles characterised the ZOU1 population. The mean value of *D* between the two populations was equal to 0.007 (Table 3.3.5).

Genetic differentiation among *Talitrus saltator, Talorchestia brito, Talorchestia deshayesii*

Genetic distances among the three species varied from 0.562 (TAB-SPA) to 1.916 (ROS-TAB1) (Table 3.3.5). The dendrogram reported in Fig. 3.3.5 synthesises the genetic relationships among all populations, showing the existence of different levels of genetic differentiation. Three main clusters were recognised:

- a first one which includes the two *Talorchestia brito* populations,
- a second one which includes the two *Talorchestia deshayesii* populations,
- a highly structured third one which includes the *Talitrus saltator* populations.

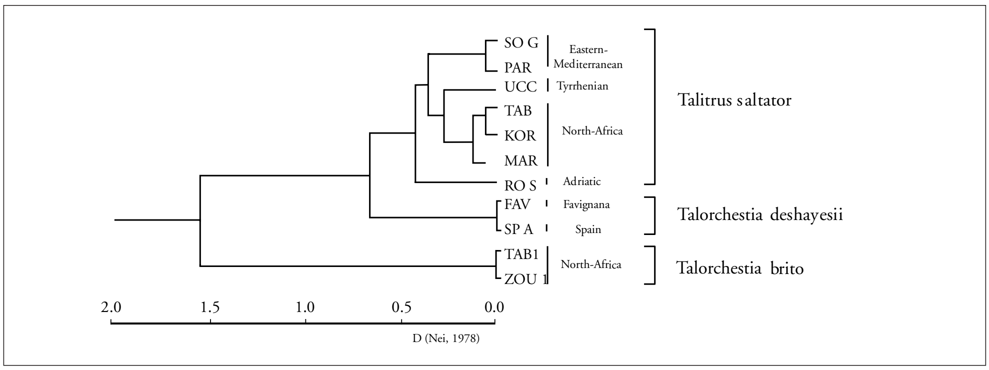

FIG. 3.3.5 *UPGMA dendrogram among study populations and species based on genetic distance values reported in Table 3.3.5*

Intrapopulation genetic variability

The mean levels of intrapopulation genetic variability are reported in Table 3.3.6.

The average degree of allozyme heterozygosity is not very high in the populations

TAB. 3.3.6 *Variability estimates of study populations and species at 21 enzymatic loci; standard errors are also given*

POPULATION	MEAN SAMPLE SIZE PER LOCUS	MEAN N° OF ALLELE PER LOCUS (A)	% POLYMORPHIC LOCI* (P)	MEAN HETEROZYGOSITY DIRECT-COUNT H_o	MEAN HETEROZYGOSITY HDYWBG$ EXPECTED -H_E
UCC	21.6± 1.1	1.3± 0.2	19.0	0.047± 0.024	0.081± 0.039
ROS	13.1± 0.9	1.1± 0.1	4.8	0.023± 0.015	0.032± 0.024
PAR	7.7± 0.1	1.0	0.0	0.000	0.000
SOG	13.3± 0.8	1.1± 0.1	4.8	0.022± 0.022	0.018± 0.018
KOR	28.7± 1.4	1.4± 0.1	23.8	0.051± 0.023	0.079± 0.034
TAB	9.2± 0.4	1.1± 0.1	9.5	0.020± 0.014	0.020± 0.014
MAR	13.8± 0.7	1.3± 0.1	23.8	0.040± 0.032	0.073± 0.033
SPA	4.0± 0.0	1.0	4.8	0.012± 0.012	0.012± 0.012
FAV	10.6± 0.4	1.1± 0.1	7.7	0.020± 0.015	0.018± 0.013
TAB1	4.9± 0.4	1.0	0.0	0.000	0.000
ZOU1	9.9± 0.5	1.1± 0.1	4.8	0.029± 0.029	0.033±0.033

* a locus is considered polymorphic if the frequency of the most common allele does not exceed 0.99
$ unbiased estimate (see Nei, 1978)

sampled and this result matches those achieved on different populations of the three species (De Matthaeis *et al.*, 1994; Scapini *et al.*, 1995). From these previous results, on the average, western Mediterranean populations of *Talitrus saltator* appeared to be more polymorphic (H_o= 0.044) than those belonging to the Adriatic group (H_o= 0.027). Mean heterozygosity appeared highly correlated with a coastal stability index, calculated as follows: presence of one/two dune belts stable or in accretion (score: 2/4), of one dune belt under erosion (score: 1), of a coastline in recession or in progression (score: -1) (Scapini *et al.*, 1995).

e. *Conclusions*

Although the results achieved must be considered preliminary, a similar trend appears between mean level of genetic heterozygosity of *Talitrus saltator* and *Talorchestia brito* populations and the stability of the coasts from which populations were collected.

The correlation between the coastal stability index and mean heterozygosity levels may suggest a positive effect of environmental temporal stability on genetic variability. This may be due to both stochastic and deterministic factors. For stochastic factors, the degree of coastal stability, causing fluctuations in population size, could affect the different levels of heterozygosity. On the other hand, the genetic variability of the populations could be related to the past occurrence of bottlenecks. For the deterministic factors, in temporally stable environments some forms of balancing selection could account for the differences in the level of heterozygosity of the examined populations.

The results reported here for the genetic structure of talitrid species have led to the estimation of the levels of genetic differentiation of North-African populations. The genetic peculiarity of this geographic group has been shown. Estimates of genetic heterozygosity and polymorphism have been provided and external factors have been suggested which could affect the genetic variability and evolutionary trend of the North-African *Talitrus saltator*.

The results from isoenzyme analysis enhance the predictive potential of this methodological approach.

f. *Support*

Equipment: in order to carry out starch gel electrophoresis a specific laboratory is needed, a number of pieces of equipment are essential and others are highly desirable. A complete listing of basic equipment are given in Murphy *et al.* (1996). In the same text it is possible to retrieve the basic chemicals required.

Software: an high number of dedicated packages are available to perform a variety of statistical analysis of genetic data; one of the most popular is Biosys-1 (Swofford and Selander, 1981). A lot of these programs are available freely through Internet (see for instance http://evolution.genetics.washington.edu/phylip/software.html).

Expertise: 1) laboratory capacity - easy after training; 2) processing of raw data - easy with the assistance of an expert researcher; 3) calculation of relevant statistics – easy with the packages available; 4) interpretation of results – comparison with existing data base is needed.

Database from the allozyme results achieved during the MECO project will be made at disposal of interested persons in Rome (Prof. Elvira De Matthaeis, University of Rome "La Sapienza"- Department of Animal and Human Biology, e-mail: elvira.dematthaeis@uniroma1.it).

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3.3.2 *DNA variation - molecular markers as tool for environmental impact evaluation* (Angela Scialpi, Maria Carmela Intrieri and Marcello Buiatti)

a. *Introduction*

One of the main causes of species extinction is the reduction of intraspecific genetic variability. The characterization of single species genetic variability and the analysis of its eventual reduction therefore could be an useful biological indicator of environmental impact.

For this purpose, key species may be selected that are abundant and common at the chosen sites and research may be carried out for the determination of levels of intrapopulation variation.

In the last few years molecular markers, revealing genetic variability at the DNA level, have been shown to be useful tools as they are putatively "neutral" and show a much higher variation level than isozymes. Polymorphism assays, that can be easily applied, are based on the polymerase chain reaction (PCR). In PCR, both strands of target DNA sequence are replicated by enzymatic DNA synthesis, initiated from two oligonucleotide primers. The temperature of the reaction is varied cyclically to allow denaturation of the DNA template, followed by hybridisation of the primers to the target sequence, and DNA synthesis. In each cycle the number of copies of the target segment is approximately doubled, resulting in exponential amplification.

Several types of molecular markers have been developed. Simple sequence repeats (SSRs) are short tandem repetitive DNA sequences with a repeat length of 1-7 base pairs. SSRs are polymorphic in the length of the repeat amplified using primers designed on the flanking regions. The detection of polymorphism is therefore due to length variation of sequences between the primers target regions. To use this type of markers extensive sequence information is needed in order to design the appropriate primers. With this aim, the GenBank (http://www.ncbi.nlm.nih.gov/Entrez/index.html) and EMBL (www.ebi.ac.uk/embl/) nucleic acid databases can be usefully searched to identify, in the selected species or in phylogenetically near ones, SSRs previously sequenced or putatively variable sequences located in introns or UTRs in genes. Hypervariable regions are homogeneous tracts containing homopurines/homo pyrimidines, AT or GC, microsatellites. The last kind of markers therefore is located in specific genes and may influence their expression. They are therefore "functional markers". As in most cases primers constructed on other organisms sequences don't give amplification because non coding sequences are very variable, primers in this case are designed on the nearest coding sequences.

To identify SSRs or hypervariable length polymorphisms acrylamide sequence gels or an automatic sequencer must be used, to be able to detect also single base pair difference. Sequence gels are very laborious to perform but automatic sequencers are most expensive, even if several companies offer payment service.

Another type of DNA markers, which don't require sequencing to design the oligonucleotide primers, are inter-simple sequence repeats (ISSR). They involve the use of microsatellite sequences directly in the design of primers for DNA amplifications. The technique is based on the use of primers consisting in the repetition of a few base pairs anchored on 5' or 3'. As other random techniques, RAPDs and AFLPs, also ISSR markers can be visualised on agarose or polyacrylamide gel and polymorphism may be detected as presence-absence of amplified bands. Therefore these markers are dominant and not able to identify heterozigosity. This notwithstanding, ISSR is an easy to apply and inexpensive method to test population variability.

b. *The strategy*

In this work, key species selected were the dune plant *Cakile maritima* and the littoral crustacean *Talitrus saltator* (as described in section 3.2). Research has been carried out therefore for the isolation of hypervariable sequences to be used as markers in the two organisms.

The plant chosen for the analyses, belongs to Crucifera family like *Arabidopsis thaliana*, a model organism for plant genetic studies whose whole genome has been sequenced. At first total DNA extraction from leaf tissue was performed according to Doyle and Doyle (1989) and a search in the GenBank and EMBL databases was conducted to find microsatellite loci previously isolated in *A. thaliana* genome (Bell and Ecker, 1994; Loridon *et al.*, 1998), with the aim to use their specific primers in *C. maritima*. Heterologous PCRs were carried out in a 50µl volume containing 100ng of DNA, 200µM of deoxynucleotide mixture, 10µM of each forward and reverse primers, 1U of Taq polymerase and 1X of provided Taq-reaction buffer and using the following profile: (i) 94°C for 5 min x 1 cycle; (ii) 94°C for 1 min, primer's annealing temperature for 1 min, 72°C for 1 min x 25 cycles; (iii) 72°C for 5 min x 1 cycle. Amplified fragments were electrophoresed through agarose gel, purified and sequenced by an automated sequencer (Sambrook *et al.*, 1989). Two loci were identified that contain repeats regions in *C. maritima*. For each locus, PCR reactions were performed using genomic DNA from *C. maritima* individuals and the products were separated on polyacrylamide gel (Sambrook *et al.*, 1989; Bassam and Caetano-Anolles, 1993), but the observed pattern did not show any difference between individuals.

Polymorphism in chloroplast genomes was also looked for. Chloroplast markers are useful in variability studies of plants, in the cases where database information is limited, because the high degree of sequence conservation renders easier the use in heterologous PCR. Consensus chloroplast microsatellite primers (CCMP), universal primers able to amplify short runs of mononucleotide repeats (Weising and Gardner, 1999), were used to amplify total genomic DNA from *C. maritima* individuals. All three primers pairs used generated PCR products, but no intrapopulation differences in fragment length were observed.

A further search in the GenBank and EMBL databases was therefore carried out looking for putatively variable sequences inserted in introns or UTR in *A. thaliana* genes. As previously mentioned, PCR primers have been designed on coding sequences, where it was possible, because of their higher conservation level useful in heterologous amplification. Five fragments containing repeat regions in *C. maritima* were thus identified. Three of these fragments [highly homologous to a putative two components response regulator protein (intron 4), cytosolic glutathione reductase (intron 5), GL1 (5'UTR), *A. thaliana* genes respectively], were variable in size in one population of *C. maritima.* These are therefore useful markers to test the genetic structure and variability of *C. maritima* populations (Fig. 3.3.6).

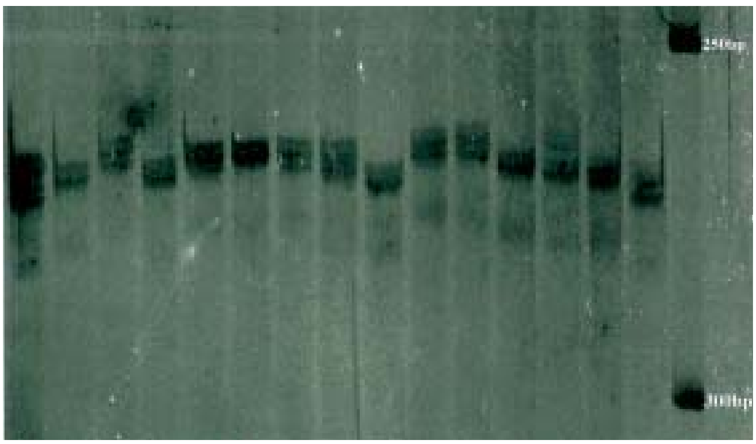

FIG 3.3.6 *Polymorphism among 15* Cakile maritima *individuals revealed by amplification with one of the isolated "functional" markers*

ISSR analysis was also performed in two populations of *C. maritima* sampled in Uccellina beach (Italy) and in White Tower bay (Ir-Ramla tat Torri, Malta, described in section 2.4) respectively, following the protocol reported by Wolfe and Liston (1998). Five out of 10 primers tested were selected to amplify genomic DNA from *C. maritima* individuals, because they were able to give good and repeatable band profiles. Amplification profiles, obtained after electrophoresis in agarose gel, showed a number of bands in all samples and polymorphic ones in single individuals. Therefore ISSR were used to test the level of resolution of molecular markers for the quantitative evaluation of variability in natural populations. For each ISSR amplification pattern, all the bands ranging in size from 2000 to 150bp were scored in 36 individuals tested for the presence (1) or absence (0) of homologous bands and compiled into a matrix. Pairwise comparisons between samples were performed using the simple matching coefficient (m/n) with the NTSYS-pc program (Rohlf, 1993). The matrices of similarity show that the variability is higher in the Uccellina population than in White Tower one. Values of similarity index in the Uccellina population are ranging between 0.51 and 1, while in White Tower population the range is between 0.65 and 1. The similarity matrices were analysed using the unweighted pair group method algorithm (UPGMA) and assembled into a dendrogram. The two populations analysed are clearly separated in the dendrogram, individuals from the White Tower population giving one main cluster, while in the Uccellina population the cluster ramifications separate with higher values of the euclidean coefficient (Fig. 3.3.7).

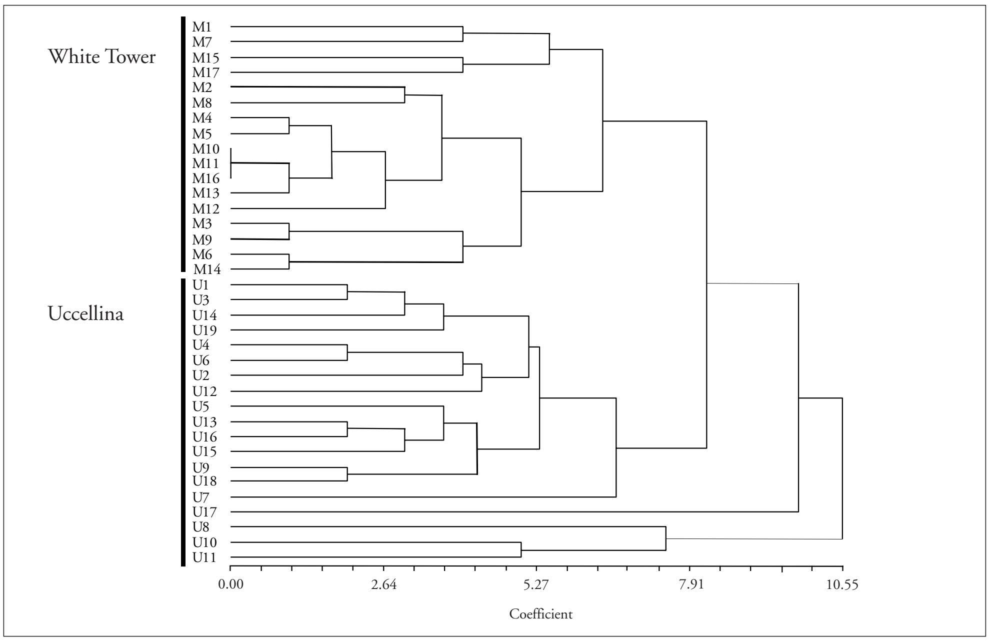

Fig 3.3.7 *Dendrogram illustrating ISSR polymorphisms among 36 individuals of two populations of* Cakile maritima*, generated by the UPGMA cluster analysis (NTSYS)*

This result suggests that the genetic variability may be higher in the Uccellina population than in the White Tower one, as expected from the known differences in the human impact, much higher in the second than in the first location.

The same strategy used in the plant, was also used to study the animal species, *Talitrus saltator*, a crustacean belonging to the Amphipoda order.

At first total DNA extraction from single individuals was performed using the DNeasy Tissue kit (QIAGEN Inc., Valencia, California) according to the manufacturer's instructions. A search in the GenBank and EMBL databases was conducted, but database informations on Amphipoda are limited. In fact microsatellites loci identified in databases were isolated in the Decapoda order (Tam and Kornfield, 1996; Tassanaikajon *et al.*, 1998; Ostellari *et al.*, 2000), therefore the amplification using heterologous primer was difficult. Moreover when heterologous PCRs were performed and amplified fragments were electrophoresed through agarose gel, purified and sequenced, the expected variable sequences were not found in the amplified fragments.

Through another search in the GenBank and EMBL databases, putatively variable sequences were identified in introns of *Peneaus* (Decapoda) genes (Bierne *et al.*, 2000). Also in this case, PCR primers were designed on flanking coding sequences. Amplified fragments did not contain the expected variable sequences.

Mitochondrial DNA analysis was also performed. In the vast majority of cases where mitochondrial genome length polymorphisms are observed, it is a direct consequence of size variation in the "control region", named the D-loop in vertebrates or AT-rich region in invertebrates. In fact this region often contains short tandemly repeated sequences (Rand, 1993). Using universal primers, the region was amplified in single individuals of *T. saltator* and amplified products showed only SNPs (single nucleotide polymorphisms), but no easy to detect length polymorphisms. Therefore this kind of marker is not useful as such in an easy and inexpensive intrapopulation study although it may be a basis for restriction polymorphisms.

ISSR analysis was then performed also in two populations of *T. saltator* sampled in Uccellina beach and in San Rossore beach (see Fig. 3.4.3A), respectively (both from the western coast of Italy). Five out of 10 primers tested were selected, because they gave many and repeteable bands. The data were treated as those of *C. maritima.*

The matrices of similarity support that the variability in the Uccellina population is higher than in the San Rossore population, also in this case in agreement with enviromental data showing a high chemical impact in the last location. Values of the similarity index in the Uccellina population are ranging between 0.50 and 1, while in San Rossore population they are ranging between 0.66 and 1. The similarity matrices were clustered using the UPGMA algorithm and assembled into a dendrogram. The San Rossore population showed only one main cluster while in the Uccelina population the cluster ramifications separate with higher value of the euclidean coefficient (Fig. 3.3.8).

Average variabilities calculated for each population show therefore that the variability is higher in Uccellina population than in San Rossore.

We can conclude that we have identified techniques for the early identification of reduction in biodiversity, likely as a consequence of increased environmental impact in both key species.

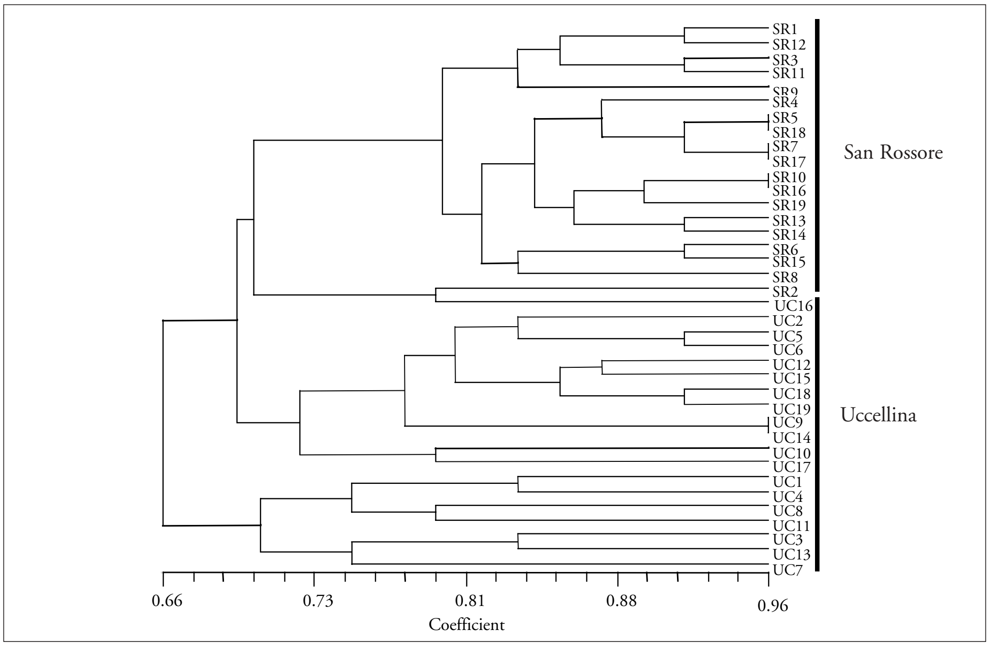

FIG. 3.3.8 *Dendrogram illustrating ISSR polymorphisms among 38 individuals of two populations of* Talitrus saltator*, generated by the UPGMA cluster analysis (NTSYS-pc)*

For *C. maritima* we have isolated functional markers that may be used to estimate heterozigosity and polymorphism in specific genes. Moreover for both organisms the ISSR technique has been shown to be a good method for fast, easy to apply and inexpensive analysis of intrapopulation variability.

The results of the analysis performed on the plant and on the animal suggest that the characterization of single species genetic variability and the eventual reduction could be a useful biological indicator of environmental impact.

c. *Equipment needed*

A laboratory where these analysis can be perform needs:
- waterbath;
- microcentrifuge;
- PCR thermocycler;
- electrophoresis equipment;
- micropipette;
- fluorimeter or spectrometer;
- standard chemicals.

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3.4 BEHAVIOURAL CHANGES AS INDICATORS OF BEACH STABILITY

Introduction (Elfed Morgan and Felicita Scapini)

Changes in animal behaviour are usually the earliest biological indicators of environmental change, and a comparison of the behaviour patterns of key species from selected beaches with those already on record provides a basis for bioassays of beach stability. These assume that population samples from stable beaches are likely to show less diverse behaviour patterns than those from beaches under threat. The rationale for such assumption is that adaptation to particular environmental features requires time (lifetime for individual adaptation, several generations for genetic adaptation). Only individuals coming from coasts relatively stable in time can adapt to the specific features of the sites of origin. Estimates of specific adaptation can thus serve as a tool for coastal stability assessment. The tests are based on the behaviour of a key species, the sand-beach amphipod, *Talitrus saltator* (see section 3.2). Other common sandhoppers, such as *Talorchestia brito* and the beach isopod *Tylos europaeus* (Fig. 3.2.1), which share the same environment, are also suitable for bio-assays, provided the data are compared with the appropriate database. The tests require reasonable numbers of live animals and are relatively easy to perform. Moreover, the animals are unharmed, and can be returned to their environment. The results are simple to analyse using software packages developed within the MECO programme. Recording equipment is available in some laboratories in the Mediterranean region, and could be made available on request (see below Fig. 3.4.1 and 3.4.4).

In the field, talitrids undergo regular nocturnal migrations up and down the shore, and it is this behaviour that has provided the basis of the bioassays. Two aspects of this behaviour: the orientation of the animals to recover the shoreline when removed from sand during the day, and the rhythmic nature of the locomotor activity, have been studied.

3.4.1 *Variation in orientation of sandhoppers removed from their burrows during the day* (Felicita Scapini, Mohamed El Gtari and Giovanni M. Marchetti)

a. *Rationale*

Although *Talitrus saltator* is normally nocturnal, clear preferred orientation patterns are evident in animals removed from the substratum during the day. Sandhoppers show a tendency to orient towards the shoreline, where, under natural conditions, they would find moist sand in which to burrow at the water's edge. Variation in the angle of orientation is easily estimated using portable choice chambers in the field (Fig. 3.4.1).

The variation in orientation is made as an estimate of adaptation to changing environments. On stable coasts, a consistent orientation of all individuals seawards would be favourable for population maintenance, but on changing coastlines many individuals would be maladapted and search for the moist sand strip in wrong directions. Individual variation would also be adaptive on bays or islands, where an array of directions would be suitable.

b. *Procedure*

Talitrus saltator (Fig. 3.2.2) were collected on site and transferred to an holding box with some moist sand and kept in the shade prior to testing. They were then released in the centre of a circular orientation chamber made of transparent Plexiglas (Fig. 3.4.1A-C). The chamber was 40 cm in diameter and it had 72 pitfall traps on its circumference. The arena was screened from wind with a transparent cover.

On site, the chamber was placed on a tripod, care being taken to ensure that the floor was horizontal. In the experiments described in section *d*, prominent landmarks were screened by covering the horizon of the arena with white rectangular cardboard, and the observers were hidden from view (Fig. 3.4.1C).

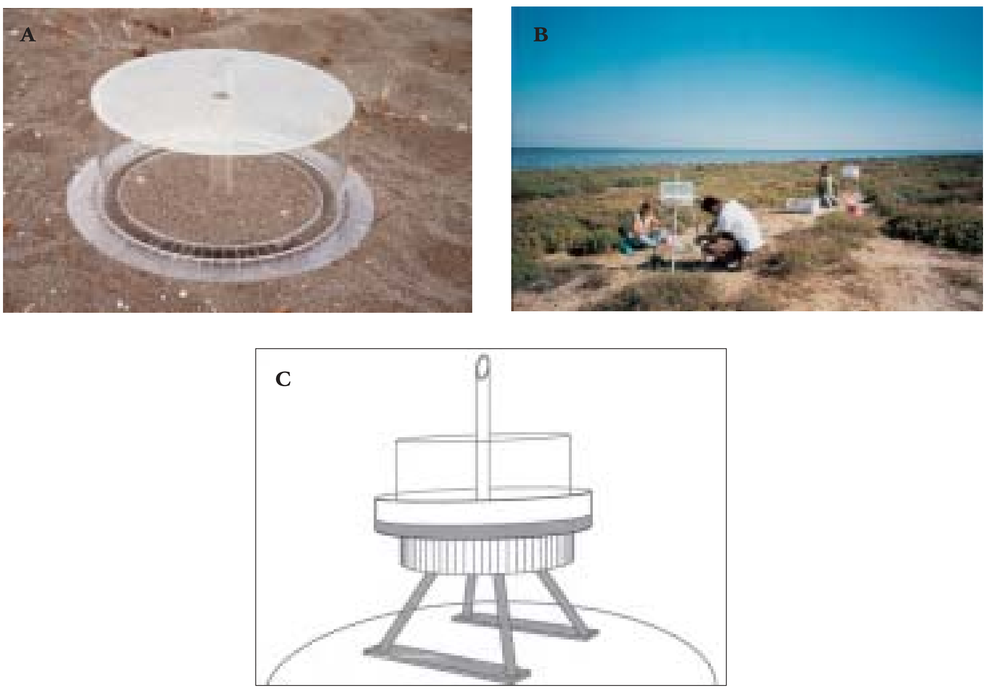

FIG. 3.4.1 *Orientation chamber used for the bioassays;* (**A**) *the arena positioned on the sand surface. The sandhoppers were introduced from the top through the tube and captured at the periphery;* (**B**) *the arena was position on a tripod to hide the experimenters from the view of the sandhoppers tested. Two arenas were used, one with landscape view screened off and the second one permitting the full view of the horizon. Here on Bessila, Kneiss Islands;* (**C**) *schematic representation of the apparatus*

In a further set of experiments (described in section *e-f*) tests were carried out under changing climatic factors (temperature, air humidity, atmospheric pressure) and different geophysical conditions, one of which allowed the animals to view the horizon through a transparent screen, the other one did not (Fig. 3.4.1B).

The animals were introduced in groups of 10 through a tube in the centre of the lid. After a period of 2-5 minutes, the tube was raised, and the animals released. The number in the pitfall traps at each compass point was then recorded. Three groups of ten individuals were released in the morning, another three groups at noon and another three groups in the afternoon, resulting in 90 independent records for one day. The angles with respect to the north and the shoreline direction were recorded to permit subsequent analysis.

c. *Data analysis*

The data were analysed using circular statistics and the mean vectors determined for each set of experiments. The distribution of the orientation directions for one day trials was calculated relative to an assumed 'normal' or mean preferred angle of orientation, using software developed within the MECO programme.

The first step in the analysis was the graphical representation of the angular distribution with respect to the north and the seaward direction (Fig. 3.4.2). Each point of distribution represented the choice of one individual. All the individuals tested from one population were cumulated in the same distribution chart.

For unimodal distributions a mean vector was calculated by summing all individual vectors (x_i) and dividing the resultant vector length with the number of vectors, using the formula:

$$r = \sqrt{(\Sigma senx_i^2 + \Sigma cosx_i^2)}/n$$

r is the mean vector length, and would vary from 0 (individuals scattered in all directions) and 1 (all individuals oriented in the same direction). Then the parameter r is a measure of the concentration of the distribution, *i.e.* of the consistency of the orientation. The mean direction μ is the direction of this resultant vector (calculated from the *arc tang*). In orientation studies, the reference directions are the geographic directions North, East, South and West, oriented clockwise as in the geographic maps. Then the first quadrant of the circle is North-East, the second South-East, the third South-West and the fourth North-West.

Statistical tests used to estimate the significance of the orientation were based on the length of the mean vector (r). The Rayleigh-test tests the significance of an unimodal distribution against a scattered distribution; the V-test is based on the projection of the mean vector on the expected direction seawards:

$$V = r \times cos\,(\mu - \mu_0)$$

where r is the mean vector length, μ its direction and μ_0 the expected direction seawards. The *V*-test then estimates the coherence of the angular distribution towards the expected direction. For unimodal distributions, the confidence limits of the mean direction were also used to estimate the significance of the deviation from the expected direction. The statistical analysis of circular distributions is explained in Batschelet (1981) and Fischer (1993).

Advanced statistical analyses using circular-linear or circular-circular correlation and multiple linear regressions were developed within the MECO project to tackle specific problems, such as the influence of environmental factors on behavioural variation (Scapini *et al.*, 2002). Environmental factors, such as sand temperature and moisture, air temperature, humidity, changing atmospheric pressure, winds, clouds, season and time differences, and human impacts may influence orientation and contribute to variation in different manners. The use of multiple regression analyses also permitted the estimation of these effects under conditions where more than one factor varied contemporaneously.

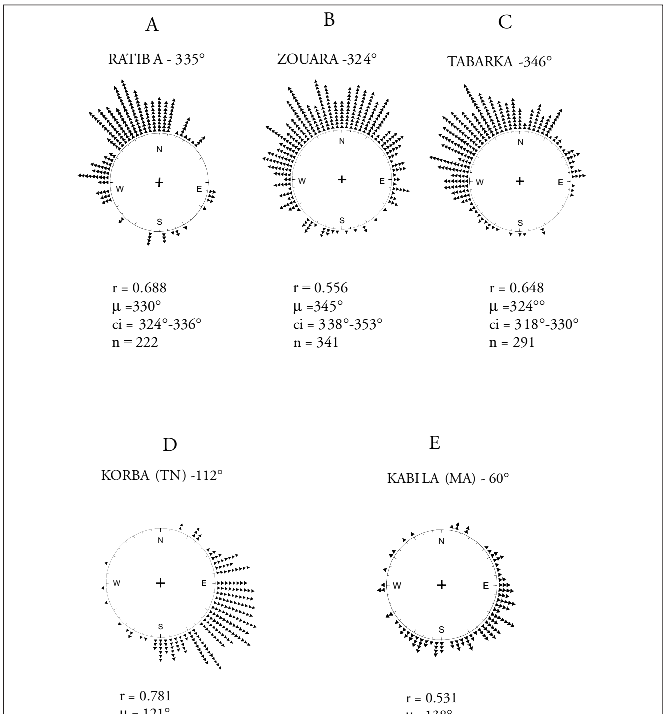

FIG. 3.4.2 *Orientation of samples of* Talitrus saltator *from:* (A) *Ratiba (northern coast of Tunisia at Cap Bon),* (B) *Zouara and* (C) *Tabarka (north-western coast of Tunisia),* (D) *Korba beach (eastern coast of Tunisia, Cap Bon) and* (E) *Kabila Beach (north-western Mediterranean coast of Morocco). For each locality the theoretical escape direction is given, perpendicular to the coastline seawards. Each little triangle in the figures represents the bearing of an individual. For each distribution the mean vector length (r), the mean direction (*μ*), the confidence interval (ci) of the mean direction and the number of individuals tested (n) is reported*

d. *Results of orientation experiments and discussion*

Within the MECO programme, the bioassay based on variation in orientation has been used to compare populations of *Talitrus saltator* in Tunisia, at Tabarka, Zouara, Ratiba and Korba, and in Morocco at the Kabila beach in front of the Smir lagoon (Fig. 3.4.2). Further populations of related talitrid species (*Talorchestia deshayesii, Orchestia montagui, O. stephenseni*) have also been studied at the Maltese Islands and Kneiss Islands (not reported here).

The distributions of North-African talitrids show a general orientation towards the sea in all the populations tested. This is shown by the high frequencies of individual angular choices in directions near the expected direction perpendicular to the shoreline seawards.

The highest concentration was shown by the population from the coast of Korba (Fig. 3.4.2D), with r = 0.781, *i.e.* close to 1 and statistically highly significant (Rayleigh-test). The worst orientation was shown by the Kabila (Fig. 3.4.2E) population with r = 0.531. Even so, this was still statistically significant.

The comparison of the mean directions of the angular distributions with the expected direction was carried out using the confidence interval (*ci*) of the mean direction. All the populations showed deviations from the exact seaward direction. The most evident was the deviation shown by the Kabila population, the smallest was shown by Ratiba population. This test may fail to show a significant deviation when the distribution is scattered.

The results of the North African populations obtained above may be interpreted in terms of beach stability versus changing coastline, confirming similar results obtained by Scapini *et al.* (1995) in Italian sandhoppers. According to the bioassay, Ratiba and Korba, both from Cap Bon beaches, however differently oriented, have the most stable coastline. In fact their orientation is more consistent towards the direction of the sea. At Tabarka and Zouara the coastline is changing. Tabarka beach has been recently affected by development for tourism development, and Zouara is subject to erosion by the sea (see sections 2.1 and 2.3). The sandhoppers from Tabarka showed a high deviation from the sea direction, and were apparently maladapted. Zouara sandhoppers were more scattered than those of Tabarka, and were adapted to re-gain the moist sand in different directions. This behavioural flexibility was frequently observed on changing beaches (Scapini and Fasinella, 1990). Similarly, Kabila beach at Smir has been severely impacted by the construction of a marina. The effect of the recent change of shoreline direction is shown by the deviation of the mean direction chosen by *Talitrus saltator* from the expected direction seawards.

e. *Analysis of factors influencing orientation using multiple regression*

The examples shown in Fig. 3.4.2 were results of experiments conducted under controlled conditions using an arena on the beach, with landscape view screened off, in late spring-summer and in warm sunny days. Under such conditions, when freshly collected adult individuals are tested, a consistent orientation seawards is expected, which would allow the animals to recover the moist sand near the waterline. But, when the experiments are conducted under changing meteorological conditions, in different seasons or using individuals of various sizes and belonging to different species, a careful analysis of the combined effect of different factors should be carried out. This method would permit quantification of the effect of environmental (changing) factors, particularly coastline stability that is of interest for monitoring purposes.

In the framework of the MECO programme, multiple regression analyses were adapted for orientation data and applied to large data sets from experiments conducted on Zouara beach in two seasons (April and October), at different times of the day, under varying meteorological conditions, on two talitrid species, *Talitrus saltator* and *Talorchestia brito* (Scapini *et al.*, 2002).

Regression methods are appropriate to study the dependence of the direction on a set of possible influencing variables, and are important to study the associations with the variables, allowing for the presence of other concomitant variables. The use of models permits better interpretation of behavioural variation in the field, and the estimation of the effect of single factors affecting orientation, which under natural conditions cannot be separated from other environmental and intrinsic factors. Statistical analysis of the effects of factors on the circular response was carried out, assuming a Projected Normal Distribution of the directions, instead of the usual von Mises pattern (used for example in the Rayleigh and V tests mentioned above). The Spherically Projected Multivariate Linear Model (SPML) of Presnell *et al.* (1998) was used. This is a parametric model, which assumes that the directions in every combination of the factors are distributed as Projected Normals, *i.e.* like the projections onto the unit circle of a bivariate standard normal distribution. The Projected Normal Distribution can be parameterised with the mean vector of the bivariate normal distribution. This is intended as a latent point of the plane whose polar co-ordinates indicate (a) the mean direction (the angle made by the vector) and (b) the concentration around this direction (the length of the vector), the further the point from the origin the more concentrated the response.

The model then assumes that the position of the mean of the bivariate normal is a function of the explanatory variables. Both the mean direction and the mean resultant length depend on the explanatory variables (predictors). When all the explanatory variables are qualitative (*i.e.* factors) the model is analogous to a multiway analysis of variance model with or without interactions. A model with the full set of interactions specifies a different Projected Normal Distribution for each combination of the levels of the factors. This model obviously can have a huge number of parameters (two for each cell) and thus simpler models can be advantageous if they do not deviate significantly from it. The models are fitted by maximum likelihood using the EM algorithm (see Presnell *et al.*, 1998 for the details).

One of the advantages of the method proposed is the possibility of exploring many models including a large number of main effects and interactions. This involves a model selection stage in the analysis, in which several models are compared. The main strategy is to start from a reasonably large model and to simplify it by backward selection. All tests are based on the likelihood ratio statistic, with the relevant null asymptotic chi square distribution. However, the choice of a final parsimonious model is based on the Akaike information criterion (*AIC*) defined by $AIC = -2\,l + 2\,p$

where *l* is the *log-likelihood* of the fitted model and *p* is the number of parameters (see Burnham and Anderson 1998 for a general discussion of AIC). On the basis of this criterion, which is a kind of penalised likelihood by which non-nested models can also be compared, the best models are those with the lowest AIC. In some cases, it is impossible to reduce the starting model and thus some improvement is obtained by introducing additional terms, like selected interactions for example.

f. *Results of multiple regression analysis and discussion*

The April data at Zouara were fitted to an additive model, which included: *sun azimuth, air temperature, air humidity and landscape view* as influencing factors of orientation. Other environmental factors, such as atmospheric pressure and intrinsic ones such as species and sex did not improve significantly the likelihood of the model, and were therefore not considered. Then the contribution of each factor was weighted by comparing the chosen model with a simpler model not containing the factor. Table 3.4.1 shows that the *sun azimuth* (depending on the time of the day) was the most influencing factor.

TAB. 3.4.1 *Contribution of each factor on talitrid arientation under the additive model fitted to the April data at Zouara*

TESTED FACTOR	TEST W VS. MODEL CHOSEN	DIFFERENCE OF DEGREES OF FREEDOM	P
Air temperature	10.376	2	<0.01
Air humidity	10.803	2	<0.01
Landscape vision	6.1511	2	<0.05
Sun azimuth	63.784	4	<0.001

The October data sets at Zouara gave different results as the best model included an interaction with *species*, that is the two species tested behaved differently with respect to the environmental factors, *sun azimuth, landscape vision, air temperature, atmospheric pressure;* the two *sexes* also behaved differently. Table 3.4.2 shows the effect of factors in the chosen October model, comparing the two species, *Talitrus*

TAB. 3.4.2 *Contribution of each factor on talitrid arientation under the additive model fitted to the October data at Zouara*

	Talorchestia brito			*Talitrus saltator*		
TESTED FACTOR	TEST W VS. MODEL CHOSEN	DIFFERENCE OF DEGREES OF FREEDOM	P	TEST W VS. MODEL CHOSEN	DIFFERENCE OF DEGREES OF FREEDOM	P
Air temperature	10.748	4	<0.05	6.270	4	0.18
Atmospheric pressure	1.810	4	0.77	88.084	4	<0.001
Landscape vision	32.284	2	<0.001	11.239	2	<0.01
Sun azimuth	14.604	4	<0.01	19.392	4	<0.001
Sex	2.651	2	0.26	10.779	2	<0.01

saltator and *Talorchestia brito* . The comparison is reported with a simpler model not containing the factor.

For *Talorchestia brito, air pressure* and *sex* were influencing factors and *landscape vision* resulted the most important factors, while *Talitrus saltator* was not influenced by *temperature* changes, but reacted to the *atmospheric pressure* changes, to *landscape vision* and *sun azimuth.*

This method permits the quantification of the effect of single environmental factors of orientation when these are presented together, as is usually the case in field experiments. The method can therefore be proposed in the analysis of bioassays of the quality of a beach, when one of the factors is an impact.

The results presented above also show how carefully the evaluation of the bioassay must be conducted, as several changing factors could influence orientation. The ideal situation would be to carry out the bioassays based on behaviour under the same environmental conditions, *i.e.* in the same season, at the same time of the day, with the same weather, using only one species and possibly one sex or age class. Then the impact factor under test only should vary.

g. *Support*

Equipment: 1) a custom-built orientation chamber, to be made from the model of Figure 3.4.1 and available from Prof. F. Scapini (University of Florence; scapini@dbag.unifi.it); 2) plastic containers for keeping the animals prior to testing; 3) tubes with alcohol to store a few samples to check species identification later; 4) magnetic compass to orient the chamber; 5) thermometer and hygrometer.

Software: self-made packages for the calculation of circular statistics and the S-Plus functions to fit the multiple regression models are available at request (Prof. G.M. Marchetti, University of Florence; gmm@ds.unifi.it)

Expertise: 1) species identification – easy after training; 2) conduction of the orientation tests – easy after training; 3) calculation of relevant statistics – easy with the packages available; 3) interpretation of results – comparison with existing database is needed.

Database from the MECO will be made at disposal of interested persons, in: Florence (Prof. F. Scapini) and Tunis (Prof. F. Charfi and M. El Gtari); see also references below.

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3.4.2 *Variation in the period of the biological clock*
(Mariella Nardi and Elfed Morgan)

a. *Rationale*

Talitrus saltator is a semi-terrestrial animal, which respires branchially and is easily subjected to dehydration. Foraging is performed mainly at night, when the animals leave the sand where they remain burrowed during the day, and migrate along the shore in search for food. These nightly migratory excursions are endogenous, in that they persist for some weeks under constant conditions in the laboratory, when they coincide with the expected night. The mean period of this activity rhythm approximates closely to the 24 hours of the solar day, although variation occurs between individuals and populations.

Variation may be derived from non optimal adaptation, as in the case of changing environmental conditions, or from individual adaptation to specific local features. This variation may be used to estimate the stability of the sand beach ecosystem.

b. *A case study - Procedure*

The animals to be used for the activity rhythm recording experiments were collected on the beaches of San Rossore – Pisa (43° 50' N – 10° 20' E) and Castiglione della Pescaia (42° 46' N – 10° 53' E) along the Tuscan coast of Italy. These two sandy beaches differ in coastline dynamics (eroded versus dynamically stable) and use (inside a natural park versus freely used and cleaned for leisure) (see Fig. 3.4.3A and B). They thus provide two different environments, which can highlight intra-population and inter-population variation.

Animals collected from the shore by hand were transported to the laboratory in a thermally insulated container containing sand from the site of collection.

Sand from the collection site, finger sifted to remove unwanted animals, was placed to a depth of about 2 cm in each of the 16 recording chambers (see Fig.3.4.4).

The chambers were of annular design, 16 cm high with internal and external

FIG. 3.4.3 *The two beaches in which sandhoppers were collected for this study:* (**A**) *San Rossore – Pisa.* (**B**) *Castiglione della Pescaia – Grosseto (Italy)*

FIG. 3.4.4 *Recording chambers used for the analysis of activity rhythm of* Talitrus saltator. *A single animal was added to each chamber, which was then covered with a sheet of polythene, secured by a rubber band. 01. Amplifier – logger; 02. Recording chambers; 03. Connection to the interface; 04. Interface; 05. Connection to the PC outside the controlled environment cabinet*

diameters of 9 and 12 cm respectively. An infrared beam spanned the radius of the annulus across a small bridge on the surface of the sand. When broken by the test animals, this caused an event to be registered on a data logging device which downloaded to a computer the number of interruptions of each beam as a separate channel, every 20 minutes throughout the experiment. A single animal was added to each chamber, which was then covered with a sheet of polythene, secured by a rubber band. This maintained the air humidity inside the chambers at suitable levels for the animals. The animals inside the chambers were also provided with dry fish food.

Activity was monitored using the equipment described and shown in Fig. 3.4.4. The animals were kept in a light-dark cycle approximating to that of the natural day-night cycle at the time of collection for the first 7 days of recording so that they could settle into the experimental conditions. They were then transferred to constant darkness for at least another week of recording. The experiments were carried out in a controlled environment room where the temperature was maintained constant at 15°± 1°C throughout.

The data of the locomotor activity of the animals recorded by the computer were analysed using a software package developed within the MECO programme. The period of the rhythm was then detected by time series analysis, using the periodogram techniques. This method of analysis is based on the Whittaker periodogram, and involves converting the data into a Buys – Ballot table from which table column mean and the standard deviation of the columns means are calculated giving the form estimates for the period scanned. The means divided by the standard deviation of the whole series give a correlation ratio that, when plotted against the period, gives the basic periodogram. The confidence levels are calculated using the following formula:

$$q_s^2 = \frac{F_s\,(f_1, f_2)}{[p\,(m - 1)\,/\,p - 1] + F_s\,(f_1, f_2)}$$

where: q_s = level of significance
p = period
m = number of columns
F_s = *FRACTILE* of F distribution

The variance of the mean period was calculated for each population. Differences between populations were calculated using the non-parametric Wilcoxon rank-sum test.

c. *Results and interpretation*

The behaviour of the animals in the recording chambers may vary considerably. Some remain inactive throughout the recording session, others may show a clear and persistent rhythm of locomotor activity, and diverse patterns may be found between these two extremes. In the light-dark cycle, activity is primarily nocturnal, but may drift out of phase with the time of expected dark when in constant darkness, as the period of the internal clock deviates from that of the 24 hours day.

Data are conventionally plotted as an *actogram* (Fig. 3.4.5). This shows the activity of each individual, recorded over successive 20 minutes intervals during each day. In the present study the level of activity in each 20 minute period has been expressed as a percentage of the highest value recorded during the 24 h of the solar day. Daily records are plotted twice, to the right and again below, to facilitate interpretation. An examination of the actograms by eye is the first analysis of the level of variation in the patterns of activity showed by the sandhoppers. Examples of actograms obtained with animals from the populations of San Rossore and Castiglione della Pescaia are shown in Fig. 3.4.5 and 3.4.6 respectively. The differences between individuals are evident for each population. Some animals showed activity well synchronised with the light-dark regimen and free-ran in constant darkness with a clear period longer than 24 hours (Fig. 3.4.5A and 3.4.6A-B). Other animals showed an irregular activity pattern which was much disturbed by noise (Fig. 3.4.5B and 3.4.6C-D).

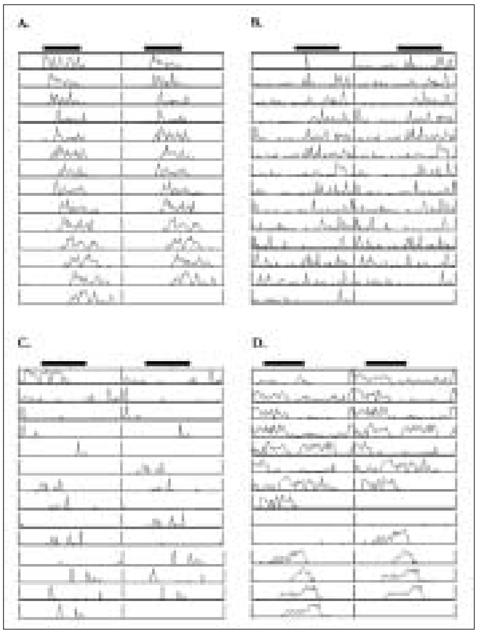

FIG. 3.4.5 *Examples of actograms. Row data of animals from San Rossore;* (**A**) *periodic animal, with a little shift from the 24 hours period in constant darkness conditions;* (**B**) *poorly periodic animal where the "signal" is much disturbed by noise;* (**C**) *poorly active animal;* (**D**) *animal showing firstly an irregular and a periodic pattern at the end, but completely inactive for few days. The black bars show the time of the dark period during the first seven days (lines 1 to 7) and the subjective dark period thereafter*

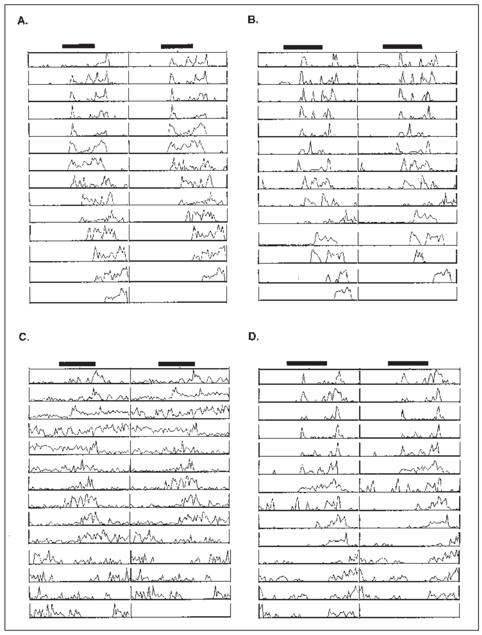

FIG. 3.4.6 *Examples of actograms. Row data of animals from Castiglione della Pescaia;* (**A**) *very clearly periodic animal;* (**B**) *periodic animal showing some noise in constant darkness conditions;* (**C**) *and* (**D**) *animals showing irregular activity with a weak periodic activity in constant darkness. Lighting regimen as for Fig 3.4.5*

However in San Rossore the variability between animals was clearer. Here the patterns of activity varied from very clearly periodic animals (Fig. 3.4.5A) to almost inactive individuals (Fig. 3.4.5C). Moreover there were differences even in the same animal throughout the recording session. One individual showed at first an irregular activity, then it was completely inactive for few days, finally it showed a periodic pattern of activity (Fig. 3.4.5D).

The free-running period (*i.e.* the period of the biological clock) has been measured by time-series analysis of the data between days 8 to 14 inclusive (second week of recording – constant darkness conditions), and examples of *periodograms* are seen in Fig. 3.4.7. The correlation ratio indicates the strength of periodicity within the data set, when scanned at different periods. The predominant period is estimated graphically as the point at which a perpendicular line from the highest point intersects the horizontal axis. The 3 lines rising obliquely from right to left across the graph indicate probabilities of significance, and only animals showing significant periodicities are selected for subsequent analysis.

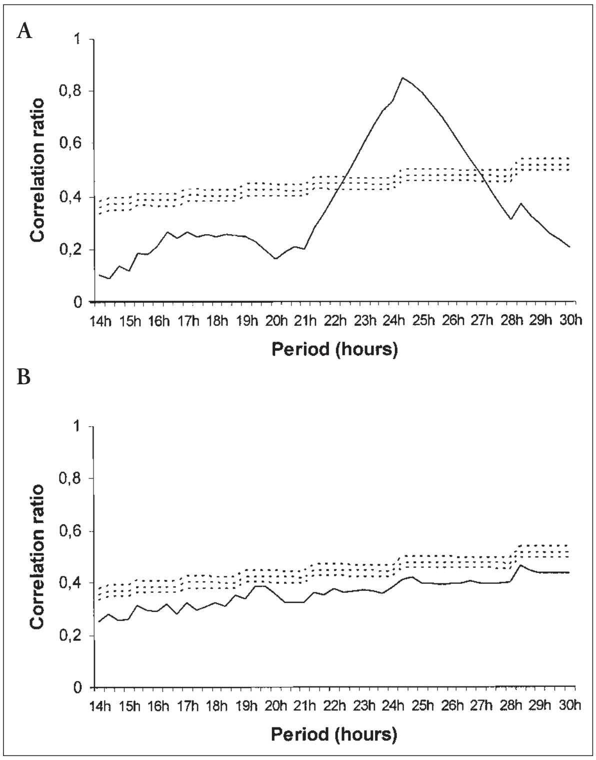

FIG 3.4.7 (**A**) *periodogram relative to an animal from Castiglione della Pescaia, whose activity was recorded in July 2000. There is a significant period at 24 h 20'.* (**B**) *periodogram relative to an animal from San Rossore, whose activity was recorded in August 2000. No significant period is present*

Comparing the two populations, it appeared that the animals from San Rossore showed a more variable free-running period than did those from the more stable beach of Castiglione della Pescaia. The mean period of Castiglione della Pescaia talitrids was shorter than that exhibited by individuals from San Rossore and there was more variability between these animals concerning the period measured. The statistical test used highlighted a significant difference between the two populations as for the mean period (see table 3.4.3).

TAB. 3.4.3 *Mean period calculated for each population, and result of the comparison between the two populations*

MEAN PERIOD	
San Rossore	Castiglione della Pescaia
25 h 5' ± 28' n = 37	24 h 27' ± 8' n = 42
Wilcoxon rank sum test: Z = - 2.3921, $p < 0.05$	

The differences between populations may be explained by the fact that on San Rossore beach (which is inside a natural park, and never cleaned) there is much detritus all over the year. In such conditions the animals can find shelter during the day and so feed continuously. They are thus not forced to concentrate their activity exclusively at night, and show a wide variability of the activity rhythm period between individuals. On Castiglione della Pescaia beach the detritus is mechanically removed once a year before summer (when there is a high density of tourists on the beach), and thus the animals cannot find any shelter where they could hide below. They are thus forced to concentrate their activity during the short spring-summer nights to avoid the risk of being active during the day when high temperatures and low air humidity represent quite adverse conditions for these animals.

A similar difference was also observed in the solar orientation of animals from these two populations by Borgioli *et al.* (1999). The distributions of directions of the orientation selected by the Castiglione samples were more consistently concentrated seawards than were those of San Rossore (see section 3.4.1 for this bioassay). This appears to be correlated with the dynamically stable coastline at Castiglione della Pescaia, whereas the San Rossore beach is actively eroded by the sea action and quickly changing. Solar orientation is known to be correlated to the animals circadian clock (Pardi and Grassi, 1955).

These results provide a comparative database for further bioassays.

d. *Support*

Equipment and software: recording equipment and controlled environment facilities are located at two sites in the Mediterranean, at the Universities of Florence and Tunis respectively, and also at the University of Birmingham, U.K. Access could be arranged (contact, see below). Software has been developed within the MECO project and is available on request (contact Dr. Efed Morgan; e.morgan@bham.ac.uk).

Expertise: training in the use of the equipment and analysis of data can be provided at the following laboratories:

School of Biosciences, University of Birmingham, UK (contact Dr. Efed Morgan; e.morgan@ bham.ac.uk)

Dipartimento di Biologia animale e Genetica "Leo Pardi", Università degli Studi di Firenze, Italy (contact Dr. M. Nardi and Prof. F. Scapini; mnardi@dbag.unifi.it; scapini@dbag.unifi.it)

Laboratory of Animal Biology, Campus Universitaire, Manar 1, Tunis, Tunisia (contact Dr. Karima Nasri)

Database: a comparative database for variation in the activity rhythm of *Talitrus saltator* from Mediterranean coasts is available at the University of Florence (contacts Dr. M. Nardi and Prof. F. Scapini).

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3.5 INTEGRATION AND INTERPRETATION OF ECOLOGICAL DATA AT POPULATION LEVEL

João C. Marques and Pedro Anastácio

Introduction

Populations of key species are usually considered as good biological targets to assess the potential impact of induced environmental changes, namely with regard to long term responses. In such case, it is particularly suitable to account for their population dynamics and reproductive biology.

Arthropods are the predominant group of sand beach fauna. Within this group, talitrid amphipods have usually wide geographic distributions, keeping nevertheless quite sensitive to anthropogenic pressures on coastal environments. Due to its abundance and distributional range, *Talitrus saltator* is usually particularly suitable to evaluate ecological adaptation and differentiation as a response to different levels of environmental stress, including human disturbance (section 3.2).

3.5.1 *Identifying qualitative inter-site variations through population dynamics studies*

From the ecological point of view, the identification of inter-site variations between populations of the same species can be achieved through comparative population dynamics studies, including the estimation of energy budgets and its relation to available food sources. From this database, models should be developed to understand adaptation to environmental gradients and changing habitats.

a. *Scope and objectives of population dynamics studies*

Study sites should be selected from beaches representing different environmental conditions along the coastline. Climatic factors, geophysical variables, degree of pollution, and recreational use must be taken into consideration for comparison. Periodic samples should be analysed for population abundance, reproductive period, sex-ratio, fecundity, and survival during development. In the case of *Talitrus saltator*, recruitment is assumed to be discontinuous. Therefore, tracking recognisable age cohorts may be used to assess field growth rates and life span.

Food abundance from the edge of the sea to the dunes should be estimated when investigating the population dynamics, and different populations should be compared throughout the year to account for seasonal variation. An “energy budget of each beach” can then be constructed, to investigate the role of local arthropods, in the case *Talitrus saltator*, in the degradation of the organic material.

b. *Field sampling protocol for* Talitrus saltator *or other sandhoppers population dynamics*
Since the goal is to carry out quantitative sampling on the studied populations, the samples must be expressed as a function of the sampled area. Additionally, as a function of the requirements of further analytical techniques, is necessary to collect a minimum of 150 specimens of *Talitrus saltator* at each sampling date. In fact, this is the suitable number for modal analysis studies addressing growth and biological features of the population.

From the shoreline to land, we may distinguish in the beach the intertidal and the supratidal areas, followed by the primary dunes. *Talitrus saltator* will be usually more abundant in the supratidal area. Nevertheless, the zonation of the age and sex classes of *T. saltator* varies with climatic conditions (storms) and with the season. For instance, in Mediterranean beaches, juveniles tend to appear closer to the shoreline than adults, while the opposite occurs on the French Atlantic coast where there are high tidal excursions. On the other hand, during the winter when the climatic gradients are more uniform, adults can be found scattered on the entire beach up to the top of the dunes.

Moreover, other abundant talitrid populations might be found in the beaches, most probably belonging to the genus *Talorchestia* and/or O*rchestia*. Specimens from these genera have about the same size as *Talitrus* and may be superficially confused by non-trained observers. It will be necessary to pay very much attention to this.

Therefore, for *Talitrus saltator*, in order to obtain a representative pattern, sampling should carried out in the following way:

I. Take the samples at regular intervals along transept guidelines, from the shoreline to the base of the dune, as indicated in Fig. 3.5.1. At least one replicate of the transept must be done. Additionally, at the level where the populations were found more abundant, take more samples randomly, to the left and to the right of the transepts (see Fig. 3.5.1). This sampling strategy will simultaneously allow to account for differential vertical distribution and to collect the minimum of individuals necessary for statistical analysis. Preferentially, sampling periodicity should be 15 days. On the other hand, rainy days must be avoided, which may cause animals dispersion.
II. Use a metal or wood-square of 0.25 m^2 to bound the sampling area. Next, using a small scoop, remove the first 20 cm of the sand surface layer, where the organisms will most probably be present. Sieve the sand through a 2 mm mesh size, throwing it into a rectangular plastic container with high walls and about 5 cm of seawater add to it. The largest animals will be retained in the sieve. Make sure to avoid animals from escaping, collecting them immediately into a plastic bottle (with some water in). The water in the plastic will prevent animals that passed through the sieve (juveniles) from escaping. At this point animals will most probably start swimming and may be caught using small hand nets or scoops. The container may also be slightly inclined to make the animals crawl out of the water and these could be captured with aspirators or with the hand net. Collect all the animals, respecting of course the minimum of 150 for *Talitrus saltator*. If the sediment in the beach consists predominantly of fine sand, you may alternatively sieve the sand through a 1 mm mesh size net bag, washing the sample within a plastic container filled with

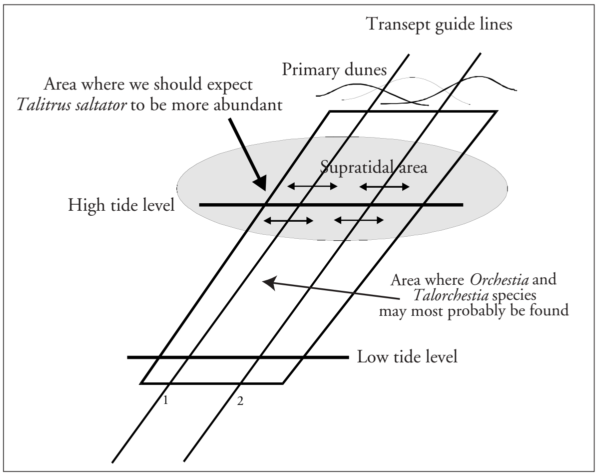

FIG. 3.5.1 *Sampling design for the population dynamics study*

water. Almost all the sand will be removed from the net bag, which will only retain the organisms and the largest particles of sediment.

III. Place all the organisms captured in a plastic bottle or bag and preserve it in 70º alcohol. Please do not use formaldehyde. Each time a minimum of 10 replicates (0.25 m^2 each) should be sampled, always respecting the threshold of at least 150 specimens collected.

IV. Additionally, qualitative samples must be undertaken to collect specimens for biochemical and calorimetric analysis. In this case, animals must be taken alive to the laboratory, separated, sexed and pooled in samples for analysis. These samples must be frozen at least at –18ºC for a period no longer than 2 months. For longer conservation periods, samples must be kept frozen at –80ºC (deep freezing).

V. For each replicate, before doing point III collect all superficial debris and sieve it through a 2 mm mesh size and preserve it in a plastic bag. In the laboratory freeze it at –18ºC for a period no longer than 2 months. This sample is intended for laboratory determination of the organic matter (potential food) available in the sampled area (mg/m^{-2}).

VI. Obtain data on maximum and minimum daily temperatures and precipitation during the study period from the closest meteorological station. These data will be very important for the modelling procedure.

c. *Laboratory procedures for biometric and biological analysis*

The goal is to collect quantitative data that will be used to describe the dynamics of the *Talitrus saltator* population, and to calibrate growth models and population dynamics models. As referred before, for each sampling date is extremely convenient to study a minimum of 150 specimens of the target species. The reason for this is that recruitment is assumed to be discontinuous for this species and therefore data on field growth rates and production will be estimated from modal analysis of size frequencies. Due to statistical requirements, with less then this number of individuals such analysis may become strongly biased. This doesn't mean that the analysis is impossible with lower numbers of individuals, only that the bias will for sure be important.

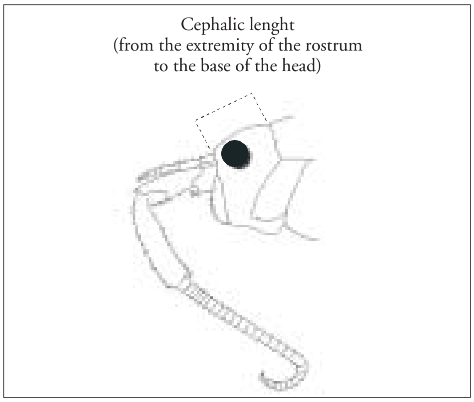

FIG. 3.5.2 *How to measure the cephalic lenght in talitrids*

The laboratory procedure should be as follows:

Biometric data: Each individual must be measured for the cephalic length (see Fig. 3.5.2) using a binocular microscope equipped with a micrometrical ocular lens calibrated with an objective micrometer. Please be sure to use a correct amplification to avoid parallax errors (suitable: 25 to 37.5 X for adultes and 50 to 75 X for juveniles). It is only necessary to measure the cephalic lenght since existing equations to estimate total length from cephalic length (type $TL = a\ CL + b$) might be used.

Each individual, after being measured, must be sexed based on:

a) Presence of copulating appendixes - males;
b) Presence of oostegites, with or without setae – females;
c) If oostegites present setae we may consider the female as mature, meaning that she will be carrying eggs soon or that she has just come from releasing them;
d) Absence of secondary sexual dimorphic features – juveniles.

The individuals may therefore be classified as:

a) male;
b) resting female;
c) mature female;
d) juvenile.

If females are carrying eggs in the brood pouch these must be taken, counted and classified. The classification for the eggs will be as follows:

a) Stage A – newly laid eggs grouped and resembling a gelatinous mass;
b) Stage B – eggs well separated, internally homogenous;
c) Stage C – embryo comma-shape and initiation of pereopods already visible;
d) Stage D – constriction of the comma clearly visible, appendages segmented, eyes visible;
e) Stage E – hatched and free juveniles.

3.5.2 *Data analysis*

a. *Length – weight relationships*

To determine the relationships between length and weight of the individuals, which will be described with an appropriated equation, at least 150 to 200, randomly sampled at each season (spring, summer, fall, and winter) must be weighted. It is desirable a 10^{-5} mg precision. Even in this case, it might be necessary to pool the juveniles. Such data will be used to determine equations of the type $W = a\,L^b$, which will allow to estimate the weight from the cephalic length.

b. *Cohorts identification and tracking*

Individuals from each sample must be kept separately (in case you may need to review anything). Data from each sample may be stored, for instance, in *Excel* tables in accordance with the example of Tab. 3.5.1.

TAB. 3.5.1 *Example of table used to store sample data*

STATION, BEACH, DATE, TRANSEPT 1, LEVEL 3, REPLICATE 2, SPECIES: T. SALTATOR

Individual number	Cephalic length	Male	Resting Female	Mature Female	Juvenile	Eggs stage A (number)	Eggs stage B (number)	Eggs stage C (number)	Eggs stage D (number)	Eggs stage E (number)
1	2.12	x								
2	1.76			x			37			
3	0.81				x					
Etc...										

These data will be further submitted to modal analysis. For this purpose, one of the possibilities is to use the Software ANAMOD, which consists of semi-graphic analytical software package, already tested in several cases studied. There are nevertheless other possibilities available in the market, based of slightly different approaches. Modal Analysis of data on size-frequency distributions will allow cohort identification and tracking, which will permit the estimation of field growth rates and productivity.

c. *Influence of environmental physicochemical factors*

Multiple regression models should be developed to correlate abundance, sex ratio, and percentage of ovigerous females, fecundity, and percentage of juveniles in the population with the environmental parameters. The fitted regression models are usually expressed as:

$$Y' = a + b_1X_1 + b_2X_2 + \ldots + b_KX_k$$

Y' - are the values of a given dependent variable (*e.g.* abundance) predicted by the equation;

$X_1, X_2 \ldots X_k$ - are independent variables (*e.g.* salinity);

The solutions are the estimate of the regression coefficients $a, b_1, b_2 \ldots b_k$. The significance of the fitted regressions is normally tested through the use of analysis of variance technique (F), and the t test for the regression coefficients. The models should be fitted with data by the method of least squares and normal equations are solved by the matrix inversion method.

d. *Production estimates*

Production estimates was based upon cohort recognition. Growth increments or production increments (P) and elimination production (E) were calculated. Approximate values of P and E for each cohort during a given time interval were expressed as:

$$P = [(N_t+N_{t+1})/2] \times (\overline{W}_{t+1}-\overline{W}_t) \ for \ \overline{W}_{t+1}>\overline{W}_t$$

$$E = [(\overline{W}_t+\overline{W}_{t+1})/2] \times (N_t-N_{t+1}) \ for \ N_t>N_{t+1}$$

N - density of the cohort in each sample date;
W - mean individual biomass in each sample date;
t and $t+1$ - consecutive sample dates;

Total values of P and E for each cohort are expressed as:

$$P = \sum_{t=0}^{t=n} [(N_t+N_{t+1})/2] \, \Delta \, \overline{W}$$

$$E = \sum_{t=0}^{t=n} [(\overline{W}_t+\overline{W}_{t+1})/2] \, \Delta \, N$$

Total values of P and E for the population is expressed as:

$$P = \sum_{n=1}^{N} P_{cn} \ and \ \Sigma = \sum_{n=1}^{N} S \, E_{cn}$$

P_{cn} and E_{cn} are the growth and elimination production of the cohort n.

P/B and E/B ratios were determined. B (mean population biomass) is expressed as:

$$B = (1/T) \sum_{n=1}^{\overline{N}} (B_n \, t)$$

T - period of study;
N - number of successive cohorts in the period T;
Bn - mean biomass of the cohort n;
t - duration of the cohort n.

3.5.3 *Modelling sandhoppers population dynamics*

A model of *Talitrus saltator* population dynamics can be used for scenario simulations *i.e.* as a tool to try to predict what would happen if the present conditions would change. The coastal line is constantly submitted to both natural and human sources of change and *T. saltator* will tend to be affected by these changes. Since it is usually present on European beaches, namely along the Mediterranean, they may serve as an indicator of the prevailing ecological conditions.

In order to build a model two main practical approaches may be used: 1. You can use programming languages such as (*e.g.*) Fortran, Pascal or Visual basic; 2. You can use one of the many software packages for modelling purposes (*e.g.* Stella or Matlab). These modelling tools allow build models of the type that will serve the present purposes. Dynamic models should be considered in order to simulate population dynamics. This implies the use of a set of variables defined as a function of time. If we would like to include the effects of the spatial heterogeneity these variables can also be dependent on space. However a strong heterogeneity should not be expected on a sandy beach. For modelling purposes a few compartments *e.g.* representing the lower beach, the upper beach and the dune may suffice or even be unnecessary.

A good rule is to follow the step-by-step modelling procedure. The following steps should be highlighted: 1- the construction of a conceptual diagram as shown in Fig. 3.5.3. The diagram will give information about the variables and processes included in the model; 2- equations can then be used to describe the model in a mathematical form; 3- verification will test the internal logic of the model; 4- sensitivity analysis will measure the impact that changes on the model will have on the model outputs. Typically one can test the effects of changes on parameters (*e.g.* birth rate); 5- a calibration of the parameter values must be performed so that the model produces values in accordance with the data used to build it; 6- whenever possible, a validation of the model should be performed. This means checking the model performance under other circumstances, *e.g.* by using data from a nearby area or from a different year.

If the reader is familiarized with Leslie matrices or with life tables this may well help to understand the way that most population dynamics models are structured. They are based on the division of the population into several age classes (Fig. 3.5.4), each of them having a certain number of individuals with only a certain number being females. Some specific characteristics are attributable to each age class, usually mortality rates and fecundity. These characteristics allow the model to calculate how the population will vary from one time step to the next one. If our time step is one day the model will calculate the number of individuals of each age class at each day by using the values on the day before.

The main problem with the previous approach when we are dealing with crustaceans is the difficulty in identifying the age classes in field samples. There is not yet a safe method for determining the age of the crustaceans. Therefore indirect methods must be applied. Size and weight are heavily dependent on the age but they are influenced by the environmental conditions for growth. Size or weight can only be used to estimate age when a previous sampling program allowed the identification of the cohorts (groups of individuals born approximately at the same time).

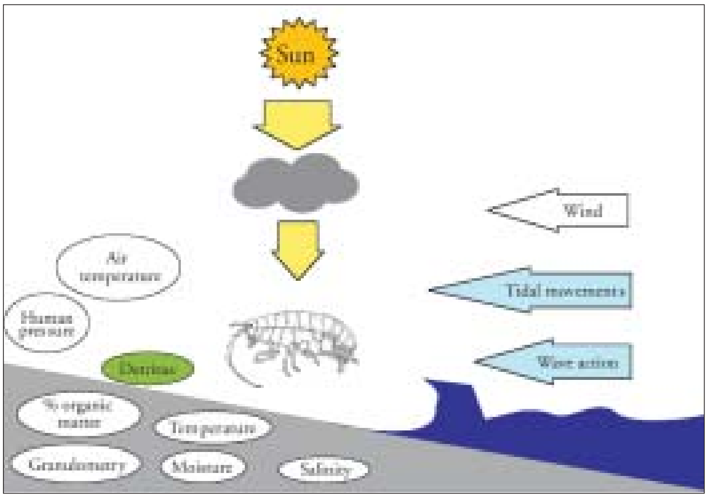

FIG. 3.5.3 *Conceptual model: external variables*

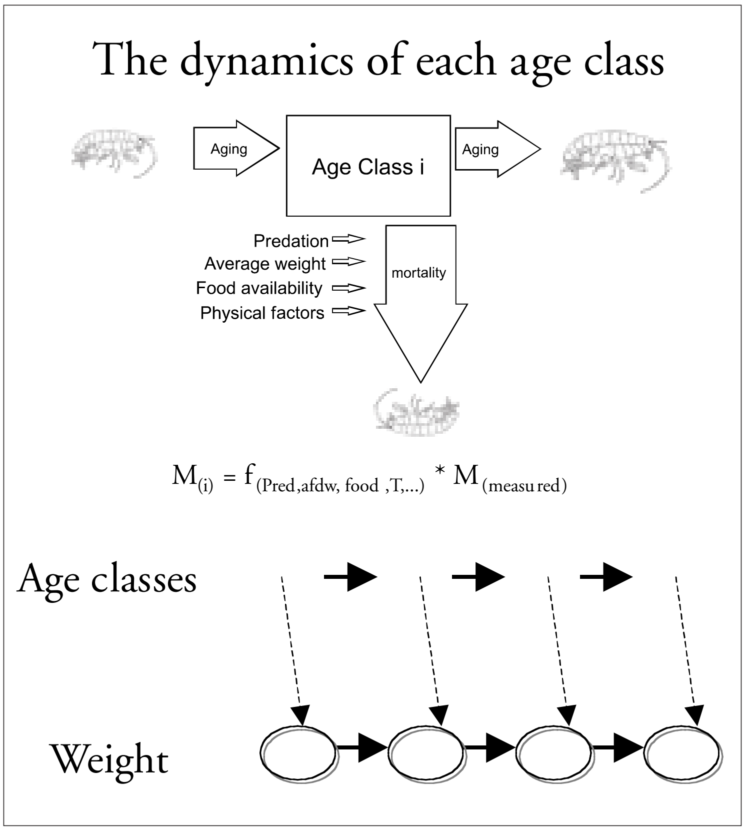

FIG. 3.5.4 *Conceptual model: simulation of the number of animals in each age class and basic structure of the model showing the interactions between different age classes considered as different state variables*

In crustaceans most of the age specific characteristics such as the fecundity or mortality can be related to weight or size instead of age. The consequence of this is that the modeller is forced to calculate the weight that a certain age class is supposed to have attained under the growth conditions that it was subjected to.

Overall, the most problematic points about modelling amphipod population dynamics are a) the need to calculate the average weight of each weight class, b) the difficulty in identifying the main factors driving reproduction at each location, and c) the quantification of the effects of the external variables such as the weather upon the dynamics of the species.

3.5.4 *Implications for integrated planning and management*

Biological and ecological information is of primer importance in terms of environmental management and planning. As explained above, reproductive biology and population dynamics studies of key stone species is a useful tool to integrate environmental changes at different time scales. In fact, within certain limits, species tend to cope with environmental changes, and when they are under environmental stress, natural or induced by human activities, their life cycles, production, and energy budgets will reflect it.

Starting from a calibrated population dynamics model, hopefully validated as well, different scenarios, corresponding to different environmental conditions, may be accounted for by changing the forcing functions and by changing the model parameters in accordance. Therefore, taking the studied species, *e.g. Talitrus saltator*, as representative of the living community (indicator), the state of the system if a given type of change occur may be anticipated. For example, the following questions might be approached:

How will the community respond to a significant increase in the number of people frequenting the beach?

How will the community react to removing the detritus from the beach *vs.* not doing it?

Several questions may be raised for a scenario where the sandy beach community, dominated by detritivores like the sandhoppers, declines or disappears. For example:

Will the sanitary quality of sand be affected since the detritus will not be processed by detritivores but simply decomposed by microorganisms?

Will the birds' community be affected by the probable reduction of available food sources?

Such questions, of obvious importance in terms of managing and planning may, in a certain extent, be approached through model simulations, which appear therefore as a powerful tool.

3.5.5 *Necessary support - Expertise*

To develop the actions described in this chapter, the following expertise and facilities will be necessary:

– Linear Statistics and Modal Analysis techniques;
– Development of population dynamics models;
– Training regarding acquisition of the necessary know-how may be obtained in a number of Institutions. In the scope of the MECO project team the laboratory that can provide this knowledge is IMAR – Institute of Marine Research, Coimbra Interdisciplinary Centre, Portugal.

3.5.6 *References*

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3.6 GENERAL EVALUATION OF BIOASSAYS

Felicita Scapini

Several different methods have been described in this chapter, which have proved their validity to assess the state of sandy beach ecosystems. However, their application may appear difficult for non scientists. There also appears some redundancy of methods proposed. Why should a monitoring programme include more than one bioassay? Why should it include bioassays at all?

Let's start from the last question. If a management plan is to be planned that takes the ecosystem into account and its sustainability, the possible impacts of the measures on ecosystem degradation/equilibrium have to be monitored regularly. Bioassays can be included in the monitoring programme, as they are repeatable and give quantitative results for comparison. Then the change in the ecosystem quality caused by the measures taken in the management plan can be estimated. Bioassays can also be used to compare environments subject to different degrees of impacts.

In particular, the bioassays based on genetic variation (section 3.3) permit us to estimate molecular variation directly linked to biodiversity (this concept is discussed in section 1.3). Bioassays based on genetic diversity are frequently used for different purposes, in agronomy and conservation of wild animal populations. We propose here their application for the evaluation of degrade of beach ecosystems. Two examples of application on animal and plant species are given, which are common in sandy beach ecosystems and can be applied to similar cases. The levels of variation in the species analysed could be used as reference for further analyses and comparisons. For the application of these bioassays a laboratory equipped for bio-molecular analyses is needed, which can be found in most universities in the Mediterranean region.

Measures of diversity at the species level (section 3.1) have been widely used to provide a baseline for conservation purposes and management of natural parks. For a correct application of this kind of bioassay in a comparative context, the sampling strategy and the expertise in the species identification are critical points, which could hamper the use of this tool in a monitoring programme. Repeatable methods of easy application are proposed here. These methods are not expensive, but time consuming. Specific expertise will be needed in the analysis phase.

Similar considerations as above can be made for the bioassay based on the analysis of the population dynamics of a key species and modelling (section 3.5). The sampling necessary, although not expensive, is time consuming, and specific expertise will be needed for the analysis. Modelling will also permit us to make predictions on the trends.

The bioassays based on behavioural variation (section 3.4) are here proposed for the first time. In principle, they estimate within species variation for beach management purpose, similarly to the genetic and population dynamics analyses. But the application of behavioural bioassays has the advantages of simplicity and speed. Experiments of orientation (section 3.4.1) of a key species can be made on site, and the animals tested can then be released. On the other hand, experiments of activity rhythms (section 3.4.2) have the advantage of automatic recording and logging. The prototype chambers, recording and logging system developed within the MECO project can be easily reproduced by an equipped electronics workshop. The methods of analysis of data proposed here are of easy application. The disadvantage of the method is the lack of background that could be used as reference or baseline for comparison.

It follows that not one optimal bioassay exists to be directly included in the monitoring programme of a management plan of sensitive coastal environments. The strategy of using more than one, at least two, independent bioassays, would thus be useful, increasing the power of both. Such a strategy was applied within the MECO project and worked efficiently. An important recommendation is that the two different bioassays should be applied independently, ideally by two different teams. The strategy would then be to start more than one independent monitoring program at the same site to estimate the impacts of the management measures. The application of different methods would both permit a reciprocal control, and highlight changes at different levels of integration and of different “grain size”, spatial and time scales.

CHAPTER 4

SOCIO-ECONOMIC ANALYSIS OF SITES

4.1 INDICATORS OF CHANGE

Alison Caffyn, Bob Prosser and Guy Jobbins

In order to develop management strategies and techniques to respond to the wide-ranging human impacts discussed in section 1.4, an adequate information base is required. Managers need relevant information so that they can monitor the site and make decisions about management actions they may deem necessary. This chapter aims to give an overview of the types of information that may be relevant for management of coastal and beach locations. It discusses how identifying indicators of change for important aspects and impacts should provide relevant information. The chapter then gives some examples of the types of method which may be useful for monitoring specific socio-economic indicators (section 4.2). Finally the need for integrated and wide-ranging assessments of the environmental, social and economic sectors is proposed (Chapter 6).

Monitoring has been defined as "the process of repetitive observations of one or more elements of the environment, for defined purposes, according to prearranged schedules in space and time and using comparable methodologies for environmental sensing and data collection" (Van der Meulen and Janssen, 1992:517). In this context 'environment' should be interpreted as not only the natural environment but also the built environment, economic environment and socio-cultural environment.

The elements of the environment to be monitored can be used as *indicators of change*. An indicator is a measure of the character, attributes or dynamics at a site. Using the concept of Limits of Acceptable Change, outlined in section 1.4.5, indicators of change will enable managers to identify desired quality standards for each element and management actions to try to maintain or improve quality. Any change in the indicator may indicate unacceptable levels of negative impact or stress or conversely, a positive impact or reduction in stress.

An example is the monitoring of the quality of sea water for pollution. Desired quality levels may have been commonly agreed (*e.g.* by the European Community in relation to their Blue Flag scheme). If the water quality falls below the desired level, managers should identify why, agree actions to address the problems and implement these in association with key stakeholders. Many beaches now regularly monitor water quality and display information for beach users.

A similar approach is useful for many other aspects of beach environments but often it is not so easy to collect and monitor relevant data. Indicators are not an end in themselves but a way of better understanding changes in the environment. Changes are likely to require management responses. Each indicator chosen should ideally be supported by a regular monitoring programme. The use of similar indicators should allow comparison between different sites.

The EU report on quality management of coastal tourism (1999) identifies how the use of indicators of change should lead to the sustainable development of coastal destinations. Certainly the focus on change is vital when considering issues of sustainability.

The World Tourism Organisation (WTO) have published guidelines on the development and use of indicators of sustainable tourism (1995). They identify a set of core indicators which should apply to any site and then a set of destination specific indicators which relate to different types of ecosystem or that are developed to meet the characteristics of particular sites (Tables 4.1, 4.2).

TAB. 4.1 *The core indicators proposed*

INDICATOR	MEASURES
1. Site protection	Level of protection or conservation designation
2. Stress	Tourist numbers visiting the site
3. Use intensity	Intensity of use in peak periods
4. Social impact	Impact of tourism on the social/cultural lives of local communities
5. Development control	Existence and implementation of environmental review procedure or formal controls over the development and use of the site
6. Waste management	The procedures for and percentage treatment of sewage at the site
7. Planning process	The extent to which there is a comprehensive planning system
8. Critical ecosystems	The number and condition of rare species and ecosystems
9. Consumer satisfaction	The measurement of visitor satisfaction over time
10. Local satisfaction	The levels of satisfaction of local people affected by tourism over time.

Adapted from WTO (1995)

TAB. 4.2 *A supplementary list of indicators for coastal areas*

ISSUE	INDICATORS	SUGGESTED MEASURES
Ecological destruction	Amount degraded	% in degraded condition
Beach degradation	Levels of erosion	% of beach eroded
Fish stocks depletion	Reduction in catch	Effort to catch fish Fish species counts for key species
Overcrowding	Use intensity	Persons per metre of accessible beach
Disruption of fauna	Species count	Number of species present Change in species mix Number of key species sightings
Diminished water quality	Pollution levels	Faecal coliform and heavy metal counts

WTO (1995)

There are different types of indicator which can be used for different purposes:

- *Warning indicators* are measures which alert managers to potential problems developing;
- *Stress or pressure indicators* measure key external factors such as population levels which will increase pressure on a resource;
- *Resource measures* address changes in the actual resource being managed;
- *Measures of impacts* aim to identify the impacts of physical, biological, social or economic changes;
- The current *management inputs and impacts* should also be measured to identify what is being done and what impacts management methods are having.

Indicators are often quantitative measures: figures, percentages, quantities, etc. However, they may also be in the form of qualitative information, that is descriptive information or data about people's opinions or views. An example of qualitative data might be value judgements about change in the aesthetic appearance of an area and how it had improved or deteriorated.

Choice of indicators is extremely important. The aim is to understand what needs to be measured and to choose a relevant and useful set of indicators. However, the potential range of information needs to be reduced to a manageable scale. The choice of indicators depends on the site's attributes and the management objectives. The general lists above provide a starting point but more specific indicators will be required at each site. If a site is to be managed to preserve rare species of fauna or flora, key indicators will focus on the health of the ecosystem and the scale of perceived threats. If the site is to be managed to reduce the impact of recreation then it will be important to measure levels, types and patterns of recreational use.

Key issues will be the availability of data and the costs (in time and money) of collecting new data. If managers need develop monitoring systems issues of reliability over time and the expertise required are extremely important.

The WTO identifies five key criteria by which to evaluate potential indicators:

1. Whether the data is obtainable;
2. Whether the indicator is both credible and easy to understand;
3. Whether the indicator enables the detection of trends over time and comparison across areas;
4. Whether the indicator is predictive of sustainability;
5. Whether threshold or reference values are available (benchmark levels).

If an indicator fulfils these criteria it is likely to be very useful. Often there may not be one indicator that will on its own measure change in a particular element of the environment but a combination of two or three indicators may provide more confirmation of change (Tab. 4.3).

Indicators focus on key areas of concern and should help ensure that management aims and objectives are achieved. *A target level may be set for each indicator* which will enable progress towards objectives to be measured (Pearson, 1996).

Tab. 4.3 *Potential indicators of change for beach environments*

BIOTIC CHANGES	ABIOTIC/PHYSICAL CHANGES	ENVIRONMENTAL CHANGES FROM HUMAN ACTIVITY	SOCIO-CULTURAL CHANGES	ECONOMIC CHANGES	CHANGES FROM MANAGEMENT ACTIONS
• Species diversity (flora and fauna) • Biomass (flora and fauna) • Diversity in behaviour (fauna) • Genetic variation • Habitat diversity and loss • Contamination levels in birds eggs/shellfish Indicators could monitor: • Corals • Fish • Insects • Amphipods • Birds • Turtles, other reptiles • Mammals e.g. rodents, seals, dolphins • Algal blooms • Vegetation Both protected and common species	• Meteorological conditions • Water quality e.g. salinity • Coastal erosion/accretion • Oceanographic changes • Wind erosion/accretion e.g. blow outs • River sediment • Dune stability • Level of water table • Climate change	• Land take for tourism, housing, industry • Levels of trampling • Air pollution • Volume/pattern of usage/ numbers of visitors • Demand for water • Water pollution • Litter/waste - volume and composition • Congestion - traffic counts, noise pollution • Aesthetic change to landscape • Aesthetic change in the built environment • Illegal construction - types, volumes and locations • Fire – number and extent of fires	• Community views • Demographic change • Visitor characteristics • Range of activities available • Visitor satisfaction levels • Safety issues e.g. number of accidents • Crime statistics • Health statistics • Communication with and participation of local people • Quality of life • Cultural diversity/mix	• Volume of businesses • Number of employees • Levels of energy use • Revenues e.g. from car parks, marina berths or entry fees • Visitor numbers and length of stay • Visitor spend per head • Fish catches • Timber production, Grazing levels • Unemployment rates • Average earnings • Economic diversity	• Beach cleaning - volumes/type of waste • Dune stabilisation - area • Fishery management - levels of liaison or enforcement • Planning regulations enforcement action • Forestry management e.g. number of trees planted • Coastal defences - number of floods • Community liaison - number of meetings, outcomes • Fire prevention techniques

The MECO project has studied a wide range of biological, geomorphological and socio-economic issues and it is possible to propose a range of potential indicators for beach environments. Although it is logical to apply a common set of indicators to all sites, their relative significance and usefulness will vary from site to site. Data for some indicators will be easily available, while for others regular monitoring by trained personnel will be required. Chapter 3 has already presented a range of ecological monitoring methodologies in detail. This section identifies a range of other potential indicators and will then discuss methodologies for undertaking monitoring for some of the socio-economic indicators (section 4.2).

The potential indicators listed in table 4.3 are not exhaustive. They are not listed in any particular order. The aim is to show how biological, physical and socio-economic indicators should be considered side by side, *i.e.* biological and physical changes are likely to have social and economic implications. The list is a useful prompt for managers to consider a wide range of potential indicators. In each case the type of data required must be judged as discussed above. If possible managers should try to choose a range of indicators which will monitor both short term and longer term changes.

Some indicators will apply at a relatively small scale *e.g.* just to part of a site. Other indicators will be available only for larger scale areas *e.g.* population statistics. This does not mean they are not useful but allowance must be made for the scale at which each indicator is measured. It is also useful to compare the results of local indicators with similar statistics for the wider area or region. This enables anomalies to be identified. Comparison of the same indicators from different sites can be used as benchmarks (as long as the same methodologies are used). This is helpful to managers in trying to understand how the dynamics of one site may vary from another and thus what responses will be most appropriate where.

The recommendation is that managers use at least two indicators from each column. More might be used from one column where this issue is of prime concern for example where human impact is very heavy or certain species are under threat. Remember, indicator information may not identify causes of impacts. Establishing causation may involve a further stage of investigation.

4.2 MONITORING METHODS

Alison Caffyn, Bob Prosser and Guy Jobbins

Introduction

A great range of methods exist for collecting monitoring data for indicators. The methods chosen will depend on the site, resources available (in terms of staff, time and finances) and the expertise of managers and other staff.

Methods need to be:

- Relatively simple;
- Use simple equipment;
- Easily repeatable;
- Reliable;
- Comparable;
- Regularly evaluated.

It is important to select sample points for monitoring carefully. The sample sites need to be adequate in number and distribution depending on the size, characteristics and variability of the site.

Remote sensing methodologies and GIS systems are becoming more frequently used for some types of monitoring. These offer advantages for certain types of monitoring but should also be judged against the same criteria as other methods. If available it would be prudent to mix the use of satellite imagery or GIS with other methods. This would provide a form of triangulation of data from various sources and will help verify results.

There are a number of difficulties associated with monitoring change (Williams, 1994). If possible managers should try to overcome these by using a range of methods and data sources and by integrating results as much as possible. However some issues are difficult to resolve.

Problems with monitoring change include:

- How to identify base levels. Is it possible to have a reference point to measure change against? This is difficult if change has been happening for some time.
- How to isolate the cause of specific impacts. Often human pressure may just accelerate changes that were already underway.
- Change may not happen in the same place as the impact *e.g.* a change in river flow may cause impacts far downstream. Similarly it may take time the change caused by an impact to be detected. If changes are not detected for several years this causes problems for management.

– Indicators are an attempt to simplify very complex processes. The complexity of relationships may make it very difficult to monitor change and identify causes.
– There may be indirect impacts from changes which may not be monitored. This is another reason to monitor a wide range of indicators as indirect impacts may be picked up through other methods.

A brief discussion of each the following methods which were used during the MECO project follows:

1. Use of secondary information and statistics;
2. SWOT analysis;
3. Beach usage - counts and observations;
4. Stakeholder analyses;
5. Visitor surveys;
6. Wider assessments.

4.2.1 *Use of secondary information and statistics*

The first methodology to consider is existing sources of data. It is usually possible to access published statistics for example on population statistics, employment rates and tourism trends. It obviously saves time and resources if a significant amount of information can be sourced from other organisations on a regular basis. Official statistics usually have the advantage of being reliable and collected on a regular basis over a number of years. However they are often for larger scale areas than specific sites and areas and thus need careful interpretation for application at the site level.

Examples used in the MECO project include tourism seasonality and accommodation supply in Tetouan province, Morocco, which were useful in our analysis of Smir, which is one of the main resort areas in Tetouan province (Fig. 4.1, 4.2).

The tourism trends data were also interesting, but because they were only available for the whole Tangiers region it was more difficult to draw conclusions from this (Fig. 4.3). The data could only be used to infer similar trends had taken place at Smir.

It is also important to check for any specialist studies which may have been carried out by government organisations, voluntary organisations and academics. These studies may provide useful in depth information on a particular topic or site, but may not be repeated regularly. Examples of this type of data identified in the MECO study included the results of a special survey of the density of people on the main Maltese beaches, using counts undertaken from a helicopter (Table 4.4). This demonstrated a very similar level of density on three of the beaches and the much less developed beach White Tower (Ir-Ramla tat-Torri) had far fewer people per m^2 of beach.

4.2.2 *SWOT analysis*

The analysis of the Strengths, Weaknesses, Opportunities and Threats is a common technique in socio-economic contexts. It can be used as a preliminary tool to identify

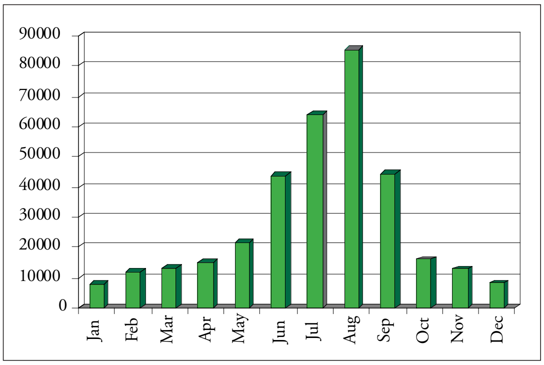

FIG 4.1 *Seasonality – tourist night, all hotels, Tetouan province, Morocco, 1999*

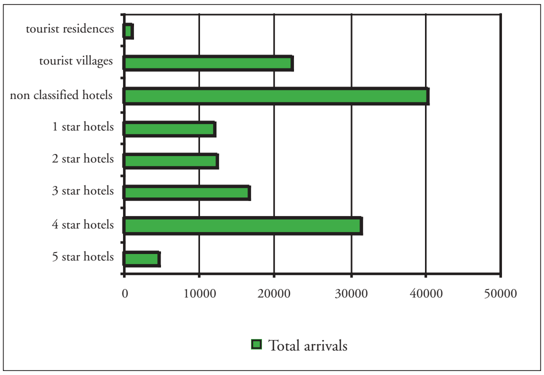

FIG 4.2 *Type of tourist accommodation, Tetouan province, Morocco, 1999*

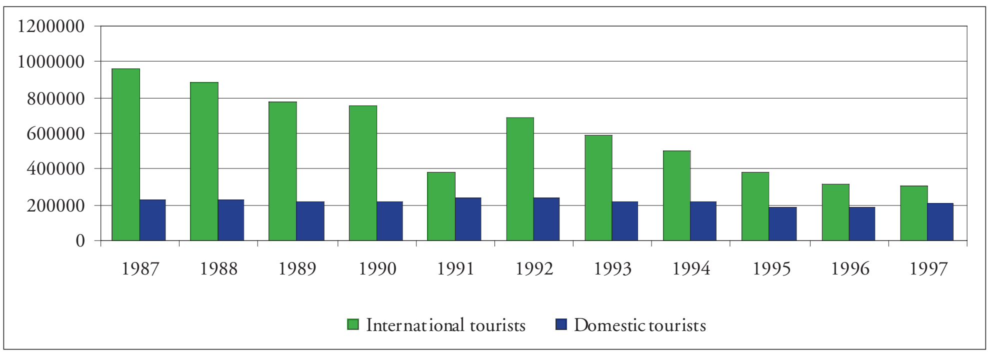

FIG 4.3 *Tourist nights, Tangiers, Morocco, 1987-1997*

and assemble a range of positive and negative issues, including opinions from a range of different people. It is able to encompass issues from the past that have had an impact, current issues and focuses attention on the future by trying to identify opportunities and threats. The technique is very simple, but provides a useful starting point for the socio-economic research. It enables an initial assessment of the constraints and poten-

TAB. 4.4 *Density of people on beaches - a Sunday in August 1999, Maltese beaches*

BEACH	TOTAL AREA M ^{2}	SANDY AREA	ROCKY AREA	PEOPLE ON SHORE	PEOPLE SWIMMING	TOTAL PEOPLE	DENSITY M^2 PER PERSON
Armier Bay	10938	8708	2235	693	348	1428	6.09
White Tower	8248	8248	-	-	-	134	61.55
Ghadira	35609	30563	5046	3088	1088	4826	6.3
Golden Bay	10880	10670	210	1044	483	1527	6.5

TAB. 4.5 *SWOT analysis for Smir, Morocco*

STRENGTHS	WEAKNESSES
Environmental • Attractive sandy beaches • Wide range of birdlife • Lagoon fauna and flora Economic • Agriculture in local villages • Tourism industry • Nearby markets in Tetouan • Local fishing industry • Services in M'diq • Water provision by new dam Socio-cultural • Good local communications	Environmental • Dam disrupted hydrological cycle • Invasion of lagoon by sea water • Restriction of dune construction Economic • Need for irrigation • Limited tourist season • Pressure on water resources Socio-cultural • Localised poverty • Restricted access along beach
OPPORTUNITIES	**THREATS**
Environmental • Legal protection • New forms of water treatment • New water management Economic • Wider range of tourism services • New forms of tourism e.g. birdwatching	Environmental • Salinisation of ground water • Increased sewage and drainage needs • Increased demand for water • New road developments • Spreading urbanisation Economic • Depletion of agriculture • Reliance on tourism Socio-cultural • Elements of drug culture • Drift from rural to urban areas • Loss of public access to beach

tialities of each site. The initial SWOT analyses can be used at later stages to prompt responses and clarify differences of opinions between stakeholders.

A sample SWOT analysis is shown in Table 4.5, undertaken during the early stages of the MECO project (1999). It presents a range of issues under environmental, economic and socio-cultural headings. It should be stressed that an issue which appears as a strength can also be interpreted as a weakness from an alternative point of view. The analysis begins to reveal the complexity of the socio-economic issues affecting a site.

4.2.3 *Beach usage - counts and observations*

Various types of data were collected through observational surveys conducted at each beach site. (The approach taken at Kneiss, Tunisia, was different as it is not a beach site, and different techniques were required.) Firstly it was important to record the numbers of beach users over time and to distinguish between recreational users and any local people using the beach as part of their business or normal daily lives. Thus regular counts were taken of people on the beach during each day of survey. In addition to exact numbers, other data were collected such as the types of activities taking place, the types of visitors present and any conflicts or problems observed. Data were recorded on specially designed record sheets and photographic records were also taken each hour (Fig. 4.4). A graph showing the results of these counts at Zouara, Tunisia, is presented in Fig. 4.5.

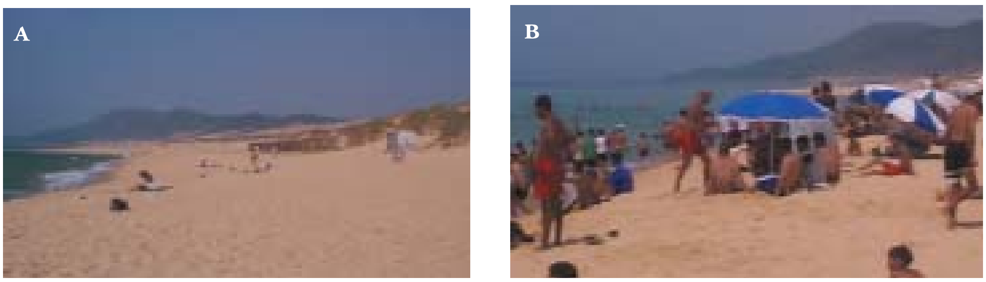

FIG. 4.4 (**A, B**) *Two photos showing contrasting volumes of usage at the same location - Zouara, Tunisia July 1999*

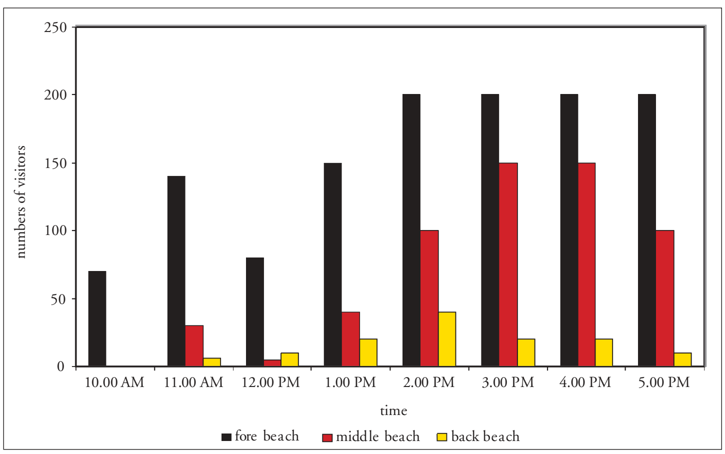

FIG 4.5 *Zouara, Tunisia – volume of visitors over time for three beach zones (July 1999)*

It was identified early on in the research process that the spatial spread of beach usage was vitally important. Thus the survey methods were designed to estimate how many people were in each zone of a beach at a particular time. Zones were iden-

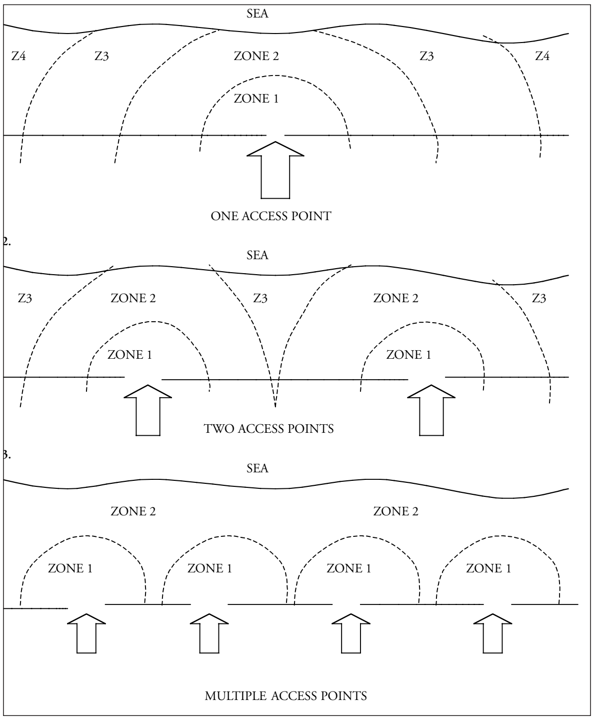

FIG. 4.6 *Basic zones - relating to beach access*

tified according to certain basic principles and applied in the same way to each site. This was a relatively simple process with the linear beaches but became problematic on Malta's pocket beaches. A sketch diagram of the basic zone types is included in Fig. 4.6. Zone 1 was heavily used but was affected by people arriving and leaving the beach and so many people preferred to settle in zone 2. Zones 3 and 4 were less used unless the volume of people was great when people spread further along the beach. It is clear that as more access points are present it is not possible to identify so many zones.

However, it is only possible to count numbers of people hourly over a given area. Once a beach becomes very busy it is only possible to record one section of the beach. In order to overcome this and also to enable an analysis of how beach usage varies along the length of each beach a transect of the beach was undertaken once each survey day. The transect was undertaken in the early afternoon in order to record the peak levels of usage along the length of the beach. An example of the results from this technique is shown in Fig. 4.7.

Fig. 4.8 shows the numbers of visitors along the length of two stretches of beach at the Morocco site, this time presented as a bar chart. It reveals the difference usage levels between the Kabila beach, used mainly by hotel guests, and the Saneer Taurus beach used more heavily by 'local' people from the surrounding region. Again these transects have also been recorded in photographic form which reveal visually not only the numbers of visitors but also types of activity being enjoyed and hence the likely impact character.

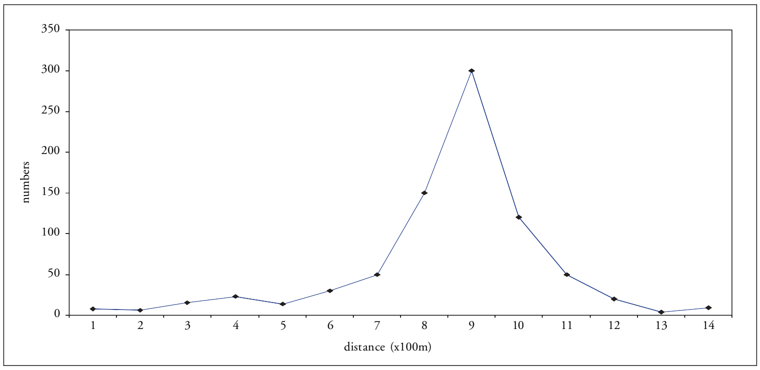

FIG 4.7 *Transect along Zouara beach, Tunisia, 4pm 4th July 1999*

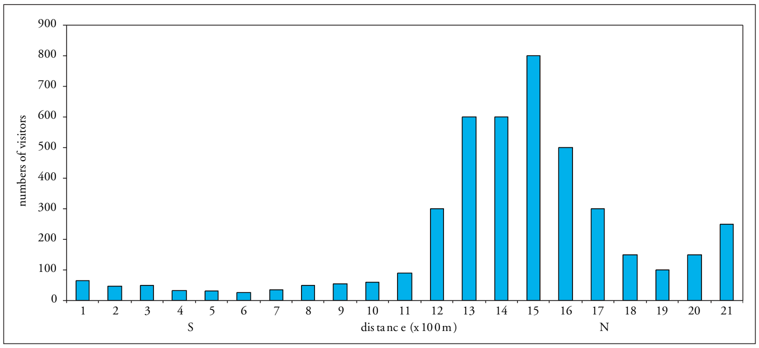

FIG. 4.8 *Transect along the beach at the Marocco site*

4.2.4 *Stakeholder analyses*

There are two types of informants that the MECO interacted with in order to undertake an analysis of stakeholders, their views and priorities. The first group included government officials and bureaucrats, whilst the second consisted of the different groups of resource users, local people and other non-governmental stakeholders. Each group were asked to provide similar information – about what they had, what they wanted, who they interacted with and how, and what problems they were experiencing

Audit of interests

An initial stage is to carry out an 'audit of interests' (Pearson, 1996), to establish each stakeholders role, responsibilities and concerns. These also help identify a sample for further contact. Sampling will almost inevitably be an opportunity sample as in most cases a representative sample of the local community will be impossible to achieve. However it is usually possible to identify key informants among most stakeholder groups. More than one informant should be identified in each stakeholder group in order to confirm information and views. During the MECO project 30-40 interviews were undertaken at each site.

Interview methodology

Semi-structured interviews can be a useful technique. They allow for a balance between the interests of the researcher and those of the subject, and provide greatest flexibility. Question topics (and translations if necessary) can be prepared in advance, and follow up questions, known as probes, can be used to clarification and elaboration. Where circumstances permit more detail can be gathered from free conversation. A core set of questions should be used for all interviewers and additional questions added where appropriate *e.g.* for farmers or owners of tourist businesses. The use of a tape recorder to record interviews may be helpful but it tends to restrict the willingness of subjects to talk freely, especially amongst government officials and it should therefore only be used when circumstances permit. It is therefore important to use a form of note taking which captures most of what is said and to review notes immediately after the interview to ensure all the points made have been recorded accurately. Questions should address the person's work or role and knowledge/experience of the site. They should also discuss the changes they have experienced, their perception of management practices and their own opinions about the issues and opportunities which are present.

Participatory research methods

The term participatory methods covers a considerable range of techniques, including focus groups, preference scoring, concept diagramming, farm sketching, transect construction and natural resource mapping. In general they are associated with a reversal from verbal to visual forms of communication, with group activity and with greater control over the information gathering process being handed to the informants. They are particularly useful where literacy skills are low or where a semi-structured interview may seem threatening.

This type of method can be very useful in discussing issues with groups of stakeholders. However considerable time is sometimes required both to arrange and carry out the exercise. A detailed map of the area might take an hour to draw up amongst a group but then might provoke considerable discussion.

Citizen participation in planning and management

Many methods are available for sharing information with local stakeholders and encouraging more active involvement. These include public meetings, focus groups, workshops, establishing an information point or office, newsletters, websites, citizen surveys, planning fora and establishing a partnership (Marien and Pizam, 1997). All methods have advantages and limitations. The most appropriate method will depend on local circumstances, the issues involved and the capabilities and resources of local stakeholders.

4.2.5 *Visitor surveys*

In order to monitor the characteristics and views of visitors to beach environments one of the most commonly used methods is a visitor survey. Visitors are interviewed using a standard questionnaire. This provides much more information than observational methods, as it is possible to ask visitors about their behaviour, views, knowledge, preferences and feelings about the site. The data can be analysed with a mixture of quantitative and qualitative methods to produce statistics about characteristics and opinions but also people's responses about the meaning the site has for them or their views on its management. Sample sizes need to be reasonable to ensure statistics produced are reliable and to monitor trends from one year to the next.

It is important to sample at both weekends and during the week as types and numbers of beach users will vary from day to day. Similarly sampling should take place throughout the season the beach is used, which could be over a six month period or more. The best sampling points should be considered where a large site is being surveyed - as again different users may prefer different areas of the beach. Sample sizes for visitor surveys are often over 1000 people, more where a large number of sample points are used or when the survey lasts over many months.

If there are a high proportion international tourists using the beach there are likely to be problems with languages as many visitors will not be able to respond to questions. Interviewers need to be carefully trained to sample users randomly and to implement the questionnaires in a standard fashion. It may not be necessary to carry out a visitor survey every year. Some recreation sites monitor only every three or five years to see if changes can be identified in users and in their opinions. If significant management changes have been introduced it would be useful to survey subsequently to monitor users responses. Visitor surveys can be large scale and time consuming exercises. They are only useful if carried out in a consistent fashion and thus great care must be taken over their implementation and interpretation. The standard questionnaire used in the MECO research is presented in the box of Fig. 4.9.

4.2.6 *Basic economic estimates*

During the MECO project we had difficulty sourcing economic information about the sites. We therefore undertook some basic estimates of the levels of employment and revenue generation in the close vicinity to each site. Asking people about how much money they earn or how much their business makes is obviously a very sensitive subject and such direct questions are rarely answered, at least not accurately. There may be a suspicion that the information may be passed to officials and much economic activity and employment around beaches may be of a semi-legal nature. However by securing responses from a small sample of key informants by asking less sensitive questions it is possible to draw up rough estimates of localised economic impacts. For example at Smir, Marocco, we spoke to at least two people in each of the following categories:
- hotel manager;
- restaurant/cafe owner;
- beach umbrella/watersport concession operator;
- refreshment kiosk operator;
- craft shop owner;
- casual 'hawker' of goods.

Simple questions were asked about:
- the number of people who were employed full time and part time;
- the numbers of visitors per day/occupancy rates;
- the length of the season;
- whether business was better this year from last and trends over the last few years;
- financial burdens such as licences, tourist taxes etc.

Often one or two people will be happy to provide more information such as aver-

Date______Location_______Interviewer______ ID__________

Introduction - Hello. We're doing a survey of people visiting this beach today. Would you be prepared to answer some questions (about why you come here and what you think about the beach)? This will take 20-30 minutes.

1. Where do you live? Town______________________________ (if local)
Region____________________________ (if domestic visitor)
Country___________________________ (if overseas)

2. Are you here on holiday? _______(tick)
or visiting friend or relatives?______
or on a day trip from home?_______

3. If you are on holiday
a) How many nights are you spending in the area? ______________
b) What type of accommodation are you staying in? ________________________
c) Where is this accommodation? _____________________________________

4. Have you visited this beach before? (ring) Yes/no
If so how often? _______________________________
Over how many years? ____________
If more than 2 years ask - Has the beach changed much since you first visited it and in what ways? ____

5. Have you or are you planning to visit any other beaches in this area? Yes/no
Which ones?____

6. How did you get to the beach today? (i.e. what was your main means of transport?)
____

7. How many people (including yourself) are there in your group visiting the beach today?
Adults_____________ Children (under 15)____________

8. What would you say is the main reason for your visit here today?
____

9. How did you know or find out about the beach? ____________________________

10. How much will you spend during your visit today (for whole group) on the following things?
Travel_________________________ Food and drink___________________
Activities_______________________ Chairs/loungers etc________________
Entertainment_____________________ Anything else (specify)_________________
Total (so overall that would be about…..?)__________________________________

11. Have you taken part (or do you intend to) in any of these activities today? (tick those which apply)
Swimming ____________Playing games__________Walking/jogging_____________
Watersports____________Boating_______________Anything else (specify)_____

12. How would you rate the following aspects of this beach?

	Excellent	good	average	poor	very poor	
	(if poor or v poor ask - why?)					
Sand	1	2	3	4	5	_________
Water	1	2	3	4	5	__________
Cafés	1	2	3	4	5	__________
Toilets	1	2	3	4	5	__________
Activities	1	2	3	4	5	__________
Parking	1	2	3	4	5	__________
Cleanliness	1	2	3	4	5	__________
Safety	1	2	3	4	5	__________

13. (If this his first visit) How would you rate this beach against your expectations before you arrived? (tick)
Better than expected_______________
A bit better than expected___________
About the same as expected__________
A bit disappointing________________
Very disappointing________________
Didn't know what to expect_________

14. What have you enjoyed most about your visit?
____

15. What have you enjoyed least about your visit?
____

16. Are there any specific ways in which the beach could be improved to make a visit more enjoyable? (anything else?)
____

17. Who do you think should be responsible for these improvements?
____

18. Do you have any other comments about the beach?
____

19. How likely are you to come back to this beach in future? (ring)
Very likely Possibly Not very likely Won't come back

20. We would appreciate it if you could provide some simple information about yourself a) Male/female (ring)
b) Age group (ring) 15-24 25-34 35-44 45-54 55-64 65+
c) Are you: (ring) In paid employment A student Unemployed Retired Housewife/husband Other
If employed in what type of job?______________________________________

Fig. 4.9 *Standard questionnaire used in the MECO research* age wages or their turnover or profit. When this information is matched with the number and size of such businesses and present information about the prices of rooms, sun loungers, goods and meals, some rough estimates of localised direct economic impacts can be made.

4.2.7 *Wider assessments*

If resources are available it would be extremely useful to undertake fuller impact assessments of all aspects - environmental, economic and socio-cultural. These would include:
- Environmental Impact Assessment;
- Economic cost -benefit analysis (Kay and Alder, 1999);
- Market assessments (of the tourist and other sectors);
- Risk assessments of various hazards such as cyclones, landslips or political unrest (Kay and Alder, 1999).

4.2.8 *Sharing information*

It is good practice to share information with scientists, managers and stakeholders. This will ensure consistency, avoid duplication, help keep everyone informed and assist in good management.

Pearson (1996) outlines key issues for sharing information:
- Establish your information needs at an early stage;
- Determine what information is held elsewhere;
- Agree on the best means of obtaining information;
- Decide who is best placed to collect it;
- Use clear and uncluttered maps;
- Decide on the best way to manage the information;
- Think long-term;
- Consider how best to convey information to all users, including the public.

4.2.9 *References*

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CHAPTER 5

DEVELOPING A MANAGEMENT PLAN

PLANS D'AMÉNAGEMENT

5.1 PLAN DE GESTION DES ZONES SENSIBLES: LIGNES DIRECTRICES

A.P.A.L.

Cadre générale du programme en Tunisie

Le Ministère de l'Environnement et de l'Aménagement du Territoire a entrepris l'élaboration de Schémas Directeur d'Aménagement des Zones Sensibles (SDAZS) littorales. Ces schémas donnent une délimitation assez précise des espaces particulièrement sensibles nécessitant une protection, une revalorisation et une gestion adaptées à leurs particularités naturelles.

Le projet MECO s'inscrit dans le cadre de la mise en œuvre de ce programme, et permet d'identifier le programme global de gestion pour chacune des deux zones sensibles choisies.

Objectifs du programme

- Conserver l'équilibre naturel du site,
- Valoriser le site en développant, si possible, une activité économique et culturelle compatible avec sa spécificité écologique,
- Mettre en place une procédure de gestion, de contrôle et du suivi du site.

Consistance du programme

Ce programme comporte deux actions principales:

1. L'élaboration des plans de gestion afin de:
- identifier et caractériser les contraintes et les potentialités socio-économiques en vue de la valorisation et de l'aménagement intégré des écosystèmes côtiers,
- définir la meilleure stratégie possible pour le développement durable de ces écosystèmes.

2. Mise en œuvre du plan de gestion
- Mettre en œuvre un système de suivi (commission de gestion, conseil scientifique, observatoire, …etc.),
- Instituer un cadre réglementaire (loi, cahier de charges, commission de gestion, …),

– Réaliser les actions de protection et de valorisation (O.N.G., A.P.A.L., Ministère de l'agriculture, privés, …).

Constitution du plan de gestion

Le premier document comprend l'étude de caractérisation des espaces naturels à protéger à savoir:

– L'inventaire détaillé des particularités, biologique, écologique, paysagère, culturelle et socio-économique du site,
– L'analyse critique des aménagements existants et programmés dans l'entité homogène composée du site considéré et ses proches environs et pouvant induire une incidence notable sur l'équilibre de la zone.

Le deuxième document comprend le schéma de gestion à savoir:

– Le plan de protection et/ou de conservation fixant:
  les moyens nécessaires à la réhabilitation éventuelle du site,
  les mesures compensatrices liées aux effets des aménagements existants et projetés,
– Un plan d'aménagement intégré et de mise en valeur des ressources naturelles,
– Un plan opérationnel de gestion.

Le troisième document défini le cadre réglementaire du protocole de suivi et de gestion:

– Suivi de l'évolution des écosystèmes à travers des indicateurs pertinents,
– Évaluation périodique de la pression anthropique.

Procédure d'élaboration du plan de gestion

L'élaboration du plan de gestion comprend trois phases:

Phase 1: Caractérisation de la zone

1. Collecte d'informations:

– le cadre physique,
– l'occupation du sol,
– les spécifités du site à savoir: le paysage, la biodiversité (faune et flore en précisant les espèces d'intérêt international et régional et les espèces endémiques), l'archéologie, la sensibilité et la fragilité, etc…,
– les menaces et sources de nuisance: l'érosion, la pollution tellurique/pélagique, la pression anthropique, etc…

2. Diagnostic

Il s'agit de procéder à l'analyse des différentes informations recueillies, d'élaborer des cartes thématiques de synthèse et d'orientation. Ce diagnostic concerne l'analyse de la situation, écologique et environnementale du site et permet d'identifier son aptitude à l'aménagement conformément aux recommandation du SDAZS:

– L'évaluation de l'état d'équilibre du site,

– L'identification des risques qu'il peut encourir,
– La détermination des évolutions tendancielles et les mesures à entreprendre pour protéger et/ou conserver le site,
– L'évaluation des potentialités du site et son aptitude à l'aménagement et à la réhabilitation, dans un contexte de développement durable.

Phase 2: Elaboration des scénarios de gestion

Présentation de scénarios

Sur la base du bilan diagnostic, différents scénarios d'aménagement sont présentés conformément aux objectifs du programme de gestion des zones sensibles à savoir la conservation de l'équilibre naturel du site et sa valorisation.

Les scénarios proposés sont accompagnés d'une étude succincte d'impact environnemental, d'une estimation financière des coûts, d'une évaluation des avantages des aménagements projetés et d'une analyse multi-critère.

Choix du scénario

Sur la base de l'analyse multi-critère proposée et en concertation avec tous les services et organismes concernés, un choix est effectué pour identifier le scénario optimal d'aménagement de la zone dans un cadre de cohérence global.

Phase 3: Schéma de gestion

Cette phase comprend trois parties principales pour l'élaboration du schéma de gestion détaillé du scénario retenu:

1. Schéma détaillé de gestion du site

Ce schéma traduit les orientations de gestion et leur répartition spatiale sur un document cartographique qui précise:
– le programme de protection et de gestion pour la mise en valeur du site et son développement durable,
– les mesures techniques, correctrices ou compensatoires dans certains cas, indispensables pour assurer la meilleure intégration possible des aménagements,
– les besoins logistiques nécessaires pour assurer la veille et le suivi en terme de gestion du site,
– l'estimation des coûts (réalisation, maintenance et suivi),
– l'étude d'impact détaillée sur l'environnement y compris l'impact socio-économique,
– le planning de réalisation du programme de protection et de valorisation pour mettre en cohérence les mesures sectorielles d'aménagement et de protection du site.

2. Mesures d'accompagnement

Il s'agit d'identifier:
– les mesures réglementaires applicables à la protection de la zone et destinées à limiter toutes sortes de nuisances, pollutions ou risques,
– les relations institutionnelles et le partenariat envisageables avec les acteurs potentiels, y compris les O.N.G., pour la bonne gestion du site,
– les indicateurs de l'évolution des sites en précisant la fréquence et le mode de leur suivi,
– les ressources financières après la réalisation des aménagements.

3. Cahier de charges pour la réalisation des travaux

Il s'agit d'un cahier de charges pour la réalisation des travaux d'aménagement relatifs au schéma de gestion adopté.

Il doit arrêter en particulier:

- les travaux de protection et leur mode de réalisation,
- les précautions à prendre lors de la réalisation des travaux,
- l'emplacement et la superficie exactes des équipements projetés,
- la nature des matériaux utilisés.

5.2 DIAGNOSTIQUE DES SITES TUNISIENS - LES FICHES DES EXPERTS

Dans cette section des exemples sont montrés de fiches synthétiques concernantes les sites de Zouara et de Kneiss et remplies par les expert MECO sur requête de l'A.P.A.L. en charge de proposer les plans d'aménagement (section 5.3).

5.2.1 *Zouara*

Nom de l'expert: A. Bayed et M.A. El Agbani
Spécialité: Ecologie marine et Ornithologie
Equipe MECO: Institut Scientifique – Rabat, Marocco
Nom du Site: Zouara

I – Potentialités (dans le domaine d'expertise) des sites tunisiens:

– Grande diversité de types d'habitats: plage, dunes bien conservées, embouchure d'oued, plan d'eau du barrage.
– Impact humain est relativement réduit, sauf en période estivale.
– Peuplement ornithologique riche en rapport avec la création du plan d'eau du barrage; Celui-ci a permis l'installation d'un peuplement ornithologique riche en espèces plongeuses particulièrement du groupe des Anatidés qui n'existait pas auparavant dans la région, ce qui constitue l'un des points positifs de ce type d'infrastructure dans des pays sud-méditerranéens où le régime pluviométrique est très irrégulier. En effet dans des pays comme la Tunisie, les lacs de barrages, constituent des milieux refuges pour les oiseaux d'eau du Paléarctique lors des périodes de migration et d'hivernage particulièrement durant les périodes de sécheresse.

II – Problèmes, contraintes et nuisances constatés:

– Forte réduction des apports sédimentaires et d'eau douce suite à l'installation du barrage de Sidi El Barrak. Ceci a engendré une réduction de l'étendue de la zone de transition reliant le tronçon aval de l'oued Zouara à la mer.
– Impact négatif de la part des estivants.

III – Recommandations de l'expert en terme de gestion

Actions recommandées:

– Maintenir un débit sanitaire en eau douce au tronçon aval de l'oued Zouara dans le but de conserver une bonne diversité en types d'habitats, en faune et en flore.
– Mettre en place dans le complexe plage-lac de barrage-embouchure de l'oued Zouara

►

d'un centre d'éducation environnementale pour les villes voisines (écoles, lycées, grand public, estivants) combinés avec des circuits écotouristiques, ce qui va donner au site une importance particulière dans cette partie du territoire tunisien. Le programme éco-touristique peut drainer des bénéfices financiers à toute la région.
– Le plan de gestion devrait être axé sur la sensibilisation et l'éducation environnementale.
Actions formellement proscrites:
Utilisation abusive de la plage.

Nom de l'expert: Lorenzo Chelazzi
Spécialité: Ecologie en particulière des écosystèmes côtière
Equipe MECO: CNR, CONISMA, Italie
Nom du Site: Zouara

I – Potentialités (dans le domaine d'expertise) des sites tunisiens:
Zouara est un site très intéressant parce qu'il est le seul en Tunisie à avoir des dunes mobiles ainsi hautes. Ici l'écosystème de la plage et de la dune est très bien préservé et c'est un des meilleures dans toute la Méditerranée avec ces caractéristiques. Le peuplement des animaux est riche en espèces et la couverture végétale est typique et semblable à celle qu'on peut trouver sur les grandes dunes des côtes Atlantiques. C'est un lieu important aussi pour les témoignages préhistoriques (ancien port et village, forêt fossile) qui se trouve le long de la côte.

II – Problèmes, contraintes et nuisances constatés:
Un des problèmes les plus importants, que nous avons constaté, est le barrage qui empêche le débit des sédiments vers la côte. Ce conduira à une diminution de la plage et à une disparition presque complète d'une dune naturelle. En outre l'ensablement de l'embouchure de l'Oued au niveau de la plage a déjà crée une stagnation des eaux et par conséquent le changement de l'écosystème de fleuve et des ses berges.
La présence de défenses sur les dunes avec de la végétation morte s'oppose aux mouvements du sable et une raréfaction des espèces animales adaptées aux dunes mobiles.
En outre la coupe de l'*Ammophila arenaria*, opérée par la population locale pour la production des paniers, en empêche la reproduction aussi bien par stolons que par graines et par conséquent la consolidation naturelle de la dune.

III – Recommandations de l'expert en terme de gestion
Actions recommandées:
Dans le plan d'aménagement du barrage il faudra considérer le relâchement périodique de l'eau pour faire en sorte qu'encore des sédiments s'écoule vers la mer. On cette façon l'embouchure de l'oued au niveau de la plage restera toujours ouvert empêchant la stagnation des eaux et il y aura un ralentissement des processus de destruction de la plage et de la dune.
Si on veut forcément fixer la dune un système beaucoup plus efficace est l'installation des plantes de *Ammophila arenaria* qu'on peut facilement reproduire en pépinières. Cette plante est capable de contenir les mouvements du sable et de consolider la dune avec son apparat radical.
On devra sensibiliser la population locale du dommage causé par la coupure de l'*Am-*

►

mophila arenaria et interdire cette pratique. On devra conseiller l'emploi d'autres matériaux pour la construction des paniers et coffins pour maintenir cette forme d'artisanat local.
Les bestiaux ne devront pas être laissés libres sur la dune. Le pâturage est une pratique que doit être absolument abolit.
On devra interdire le passage sur la dune à pied et avec autres moyens de locomotion et permettre l'entrée à la plage seulement en certains endroits. Le passage vers la mer pourra être facilité par le mise en place des planches en bois qui retiendront les baigneurs de marcher sur la dune et ses plantes. On conseille de mettre des panneaux pour signaler les comportements permis.
Les poubelles devront être nombreuses et les ordures ramassées tous les jours pour empêcher qu'ils deviennent des pièges à attraction pour les animaux (invertébrés et vertébrés).
S'il y a un projet de construire une installation touristique, on devra avoir la précaution d'emporter tous les débris de chantier.
On suggère de préserver et promouvoir les sites préhistoriques et les témoignages d'une forêt fossile au sud de l'oued Zouara, aussi bien que les ruines d'un antique port sur le bord droit de l'oued. Un petit musée pourvoira à contenir les pièces archéologiques et l'histoire de cette zone.
Actions formellement proscrites:
Il faudra interdire l'entrée à la plage dehors d'endroits permis. La plage et la dune ne devront pas être nettoyées avec moyens mécanisés, mais seulement manuellement en laissant tout le matériel organique. Les quais et les barrages dans la mer ne devront pas être construits, parce que, en déviant les courants marins, ils provoquent seulement des érosions et des cumuls des détritus sur la côte, même à grande distance, sans empêcher l'érosion de la dune de Zouara.

Nom de l'expert: Alison Caffyn and Guy Jobbins
Spécialité: Socio-economy
Equipe MECO: CURS, UK
Nom du Site: Zouara

I – Potentialités (dans le domaine d'expertise) des sites tunisiens:
Opportunities include:
To develop a new model of tourism development for Tunisia – a viable and sustainable tourism development, integrated within the local area – an opportunity to get it right.
To draw on good practice and examples from elsewhere in order to maximise local benefits and minimise harmful impacts.
To use the new dam and reservoir as both a land-based and water based recreational resource for local people and tourists for fishing and boating.

II – Problèmes, contraintes et nuisances constatés:
Problems and constraints include:
How to develop an economically viable tourism development without compromising the peace, wildness and open spaces so valued by visitors.
The short tourism season.

►

Use of water resources.
Infrastructure including waste disposal, particularly sewage treatment.
Danger of fire to the forestry areas.
Accessibility of Zouara – very car dependent.
Lack of appropriate labour force locally – need for training and management expertise.
Safety – *e.g.* strong currents in the sea and near-shore boating activities.
Tourist activities – what activities are appropriate, where and with what environmental impacts?
How to ensure benefits for local people and businesses, rather than leakages out of the local economy.
Underdeveloped agricultural communities in the forest.

III – Recommandations de l'expert en terme de gestion:
Recommended actions:
– Develop a business plan for the tourism development with full costings and market assessment to ensure there is a market for the type of development proposed, at the scale of development proposed and given the seasonality of the destination.
– Undertake market testing – what is the target market? What will they want to do? What will they pay? What is the size of the market and what is the competition? How will seasonality impact on the development?
– Conduct a full environmental impact assessment to assess impacts on dunes, forest, sea and in particular to assess demands for water, waste disposal and fire risks.
– Develop an integrated management plan for the wider area which includes the tourism development within the management of the forest, dam, coastline and wider catchment area.
– Develop management practices that are adaptive and flexible, decreasing the reliance on fixed plans and better utilising resources distributed to local and regional levels.
– Consider forms of more decentralised integrated decision-making and planning
– Consult with local stakeholders to find out more about local needs and opportunities and to give local people a stake in the new development.
– Conduct an economic impact analysis of the proposed tourism development to identify the number of jobs which will be created and the effects on the local and regional economy. The level of 'embeddedness' in the local economy is crucial so that benefits will be felt locally. Do not rely on the 'trickle down' of benefits to local people.
– Monitor the impacts of the dam and reservoir.
– Make investment companies prove how they will ensure local benefits and attach conditions to ensure this happens.
– Create a commission to examine the impacts of the dam's construction on local communities, review compensation policies and calculate total economic values of water resources using modern resource economic assessment techniques.
– Develop community institutions, fund agricultural extension and community development workers, involving NGOs such as APEL to embark on a programme of integrated rural development.

5.2.2 *Kneiss*

Nom de l'expert: Moncef Gueddari et Ameur Oueslati
Spécialité: Géologie et géomorphologie
Equipe MECO: Tunisie, FST
Nom du Site: Kneiss

I – Potentialités (dans le domaine d'expertise)des sites tunisiens:
Les potentialités, sur le plan géologique et géomorphologique, tiennent surtout à la qualité des paysages naturels, à l'existence de formes de terrains et d'écosystèmes spécifiques, ainsi qu'à une dynamique du milieu particulière en rapport avec un environnement physique original.
Le site et ses environs offrent, en plus des potentialités pour le développement économique (tourisme, pêche, etc.), de grandes opportunités pour la recherche scientifiques.
– Des potentialités paysagères: Malgré la faiblesse de la topographie, la région montre des paysages naturels d'une beauté exceptionnelle et d'une grande originalité. Les falaises des environs de Skhira, les hauts-fonds largement exondés ou envahis par la mer au gré de la marée, les îlots perdus au milieu de ces hauts-fonds et les chenaux de marée sont les principales composantes de cette originalité.
– Une originalité sur le plan morphologique et sédimentologique: la morphologie sous-marine et la topographie du rivage, d'une part, et l'importance de la marée, d'autre part, ont favorisé la mise en place de formes et de modelés côtiers uniques en leur genre ou peu connus ailleurs dont, en particulier, des marais maritimes à slikkes et schorres caractéristiques. Ces formes, qui montrent dans le site de Kneiss un grand développement, sont très peu représentées en Méditerranée.
De telles conditions naturelles ainsi que le grand développement des hauts-fonds et les caractéristiques de la topographie sous-marine sont également à l'origine d'une dynamique sédimentaire originale.
– Un patrimoine géologique et archéologiques indéniable (coupes géologiques et dépôts marins et continentaux significatifs, vestiges archéologiques préhistoriques et historiques). Les rares coupes géologiques, lorsqu'elles existent, sont souvent très significatives. Elles permettent la connaissance des caractéristiques de la dynamique des milieux côtiers et la compréhension des tendances de l'évolution récente des littoraux.
Les formes et dépôts ainsi que les vestiges archéologiques constituent des repères précieux pour la reconstitution des étapes de cette évolution et des paléoenvironnements; ce qui double leur valeur patrimoniale. Une telle démarche est toujours d'un grand intérêt pour la définition des aptitudes à l'aménagement.
– Un environnement encore peu anthropisé: il faut y voir une chance, les espaces côtiers non ou faiblement aménagés étant devenus rares. Ceci permet, mieux qu'ailleurs, la valorisation des atouts de la nature. Cet intérêt est en fait doublé par la valeur écologique et par la biodiversité de l'ensemble des hauts-fonds, des îles et du rivage.
- Un grand intérêt scientifique: par les caractéristiques-potentialités qui viennent d'être énumérées, ce terrain offre de grandes opportunités pour développer de nouveaux axes de recherche en Géologie et en Géomorphologie, relatifs aux milieux côtiers.

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II – Problèmes, contraintes et nuisances constatés:
– Des problèmes d'érosion marine: les principaux problèmes constatés sont relatifs à l'érosion marine. Certains secteurs (notamment au droit des principaux cours d'eau et au pied de quelques falaises), connaissent une progradation de leur rivage, mais la tendance générale est pour le recul du trait de côte. Les îles, notamment les plus petites d'entre elles, sont les plus menacées.
L'avancée de la mer est facilitée par la faiblesse de la topographie, le caractère tendre des formations géologiques battues par les vagues et la tendance à la subsidence des terrains côtiers.
– Des problèmes d'érosion hydrique: l'érosion hydrique assure une alimentation sédimentaire parfois importante aux estrans et peut, de ce point de vue, être considérée comme bénéfique au rivage. Mais dans certains cas elle est en train de menacer un patrimoine pédologique déjà faible, des structures archéologiques et des propriétés agricoles. Le problème est parfois devenu épineux, notamment dans l'aire des falaises et dans les marges externes des plateaux dans lesquels elles sont taillées.

Nom de l'expert: A. Bayed et M.A. El Agbani
Spécialités: Ecologie marine et Ornithologie
Equipe MECO: Institut Scientifique – Rabat, Marocco
Nom du Site: Complexe des zones humides des Îles Kneiss

I – Potentialités (dans le domaine d'expertise)des sites tunisiens:
– Originalité physionimique du site à l'échelle de la Méditerranée, marquée par l'existence de grandes vasières et de chenaux découvrants à basse mer; grande amplitude de marée permettant l'installation de conditions écologiques très variées.
– Larges superficies de vasières, lieu de nourrissage d'oiseaux d'eaux, et tout particulièrement des limicoles.
– Grande diversité de biotopes et d'habitats pour la flore et la faune, ce qui laisse supposer une biodivesité élevée conférant à ce site une importance toute particulière.
– Existence de nombreuses zones occupées par les phanérogames marines dont l'intérêt mondial est croissant et qui développe et qui permettent le développement d'une faune spécifique et particuilèrement abondante et diversifiée.
– Existence d'îlots favorables au développement d'une végétation spécifique adaptée et permettant la nidification de larges effectifs d'oiseaux, notamment les laro-limicoles.
– Forte diversité et abondance de l'ornithofaune se nourrissant de vasières témoignant d'une grande abondance de microfaune et macrofaune benthique qui trouvent ici les conditions favorables à leur développement compte tenu de l'arrivée d'eaux douce et par le fort marnage que connaît ce complexe.
– Intérêt socio-économique pour la population riveraine par le développement des activités de pêche de poissons et de ramassage de mollusques.
– Potientielités éco-touristiques indéniables pour ce milieu tellement particulier et diversifié.
– Vu les importants effectifs d'oiseaux d'eau que peut accueillir le site en hivernage et durant les périodes de migration, le site répond amplement au critères de sélection de la convention de Ramsar et peut être considéré comme site d'importance internationale.

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Pour un certain nombre d'espèces d'oiseaux d'eau, le complexe des zones humides des Îles Kneiss, représente un site clé à l'échelle de toute la Méditerranée occidentale.

II – Problèmes, contraintes et nuisances constatés:
– Forte pollution par les déchets en plastique.
– Surexploitation des ressources halieutiques (pêche et ramassage de mollusques).
– Absence de réglementation de la pêche dans le complexe.
– Dérangement des nicheurs et ramassage des œufs pendant la saison de reproduction au niveau des îles.

III – Recommandations de l'expert en terme de gestion:
Actions recommandées:
– Organisation et réglementation des activités de pêche et de ramassage des mollusques.
– Réglementation des accès aux îlots.
– Suivi de la qualité des apports des affluents continentaux vers complexe.
– Etablissement de programme de suivi des populations d'oiseaux d'eau pendant les périodes de migration, hivernage et reproduction.
A*ctions formellement proscrites*:
– Accès aux îlots pendant la période de reproduction des oiseaux.
– Utilisation des engins de pêche qui perturbent l'écosystème et provoquent la mortalité d'espèces non ciblées par la pêche.
– Adapter le nombre de barques (bateaux) et des pêcheurs en fonction des potentialités halieutiques du complexe des Kneiss.
– Perturbation excessive des vasières par le piétinement provoqué par les ramasseurs des mollusques.

Nom de l'expert:	Alison Caffyn, Guy Jobbins
Spécialité:	Socio-economy
Equipe MECO:	CURS, UK
Nom du Site:	Kneiss

I – Potentialités (dans le domaine d'expertise) des sites tunisiens:
Opportunities include:
To develop a more economically and environmentally sustainable fishery.
To identify and develop alternative sources of income for local communities and diversify the local economy.
To improve access to health and education for the local population.
To conserve valuable marine and land environments and habitats.
To explore potential for small scale ecotourism, perhaps based on ornithology.

II – Problèmes, contraintes et nuisances constatés:
Problems and constraints include:
The closure of the shell fishery.
Pollution in the Gulf of Gabes.
Unsustainable and illegal fishing techniques.

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Poverty of local population.
Declining fish stocks.
Power and role of 'middlemen' who sell fish at market.
Lack of options available to fishermen and local communities.
Ineffective management mechanisms – incentives, penalties and appropriate forms of credit.
Limited water resources.

III – Recommandations de l'expert en terme de gestion:
Recommended actions:
Introduce new management mechanisms which involve and educate the fishermen and seek their co-operation.
Support the development of better and more flexible co-operative arrangements for fishermen to buy equipment, sell their fish and work together. Current co-operatives are not accessible to fishermen due to entry requirements and conditions.
Examine means of strengthening enforcement, including the recruiting of local fishermen and shore patrols.
Identify more funding for outreach or extension workers to work with local communities to identify areas of need and opportunity and develop closer relations between local people and the administration.
Disseminate information about fishery and environmental management more effectively to all government departments, local managers and the local community and develop better communication mechanisms.
Work with local officials to develop a 'listening mentality' towards local people.
Discuss ways of limiting or regulating the power and control of 'middlemen', or of involving them in the governance process.
Develop alternative forms of economic activity in the area, for example are there opportunities for women to diversify family incomes?
Develop social capacity amongst the local population through education and the development of more social structures including community institutions as a precursor to co-operatives.
Conduct further research into marine pollution and its impacts on marine and terrestrial ecosystems, particularly the threats to humans, fish stocks and birdlife.
Consider establishing territories for artisanal fishers, thereby establishing community resource rights.
Actions forbidden:
Forbid the use and possession of bottom trawling gear *e.g.* the 'kess', in all fisheries.
Other suggestions:
Rely less on expensive infrastructural development *e.g.* the harbour at Zaboussa, and invest more in community projects, agricultural extension workers etc.

5.3 ÉTUDE DE CAS: PLAN DE GESTION DU SITE DE ZOUARA-NEFZA ET DU SITE DES ÎLES KNEISS (TUNISIE)

Habib Ben Moussa, Fadhel Baccar, Lassad Douffani, Anissa Ksia, Mohamed Hedi Sfar et Sihem Slim

Sur la base du diagnostic établi pour les deux sites de Zouara et de Kneiss et de l'analyse de leurs situations particulières, une synthèse a été établie par chaque expert intervenant dans l'équipe d'études afin de définir, de son point de vue, les facteurs de sensibilités du site et ses aptitudes à l'aménagement (section 5.2).

Ceci a permis de dégager les orientations de protection, de valorisation et de gestion et de définir les actions capables de protéger le site et de lui garantir les conditions favorisant le maintien de son équilibre environnemental et paysager.

5.3.1 *Premier cas: Le site de Zouara*

a. *Rappel des facteurs de sensibilité du site*

Si le site fait preuve d'une certaine richesse écologique et naturelle, cela ne l'empêche pas d'être également l'objet de diverses contraintes et menaces à l'affût du maintien de son équilibre environnemental. Celles ci se résument dans les faits suivants:

Les impacts directs et indirects du barrage de Sidi El Barrak : Cet ouvrage constitue, à priori, la menace la plus importante qui risque de générer de graves nuisances au site de Zouara. On assiste de à présent à plusieurs phénomènes dont principalement:

- Une stagnation des eaux du côté de la plage ralentissant le débit de déversement dans la mer ce qui provoque par conséquent, une stagnation constante des sédiments au niveau de la plage et un blocage de l'embouchure de l'oued au niveau de la plage,
- Une pollution des eaux du côté plage causée par le ralentissement du débit d'eau,
- Une disparition par submersion par les eaux, des terres cultivées aux niveaux des berges de l'oued,
- Une perturbation de l'équilibre sur les plans écologique, urbain et socio-économique.

En terme de prévisions, on s'attend aux conséquences suivantes:

- Un ralentissement négatif prochain de la production halieutique et de la recharge en sable de la plage du à la mise en service du barrage,
- Une diminution notable de la surface de la plage,
- Une disparition potentielle de la dune naturelle.

La raréfaction des espèces animales adaptées aux dunes mobiles par la mise en défens pratiquée sur les dunes et la présence de végétation morte qui entravent le mouvement du sable.

Le développement incontrôlé de l'habitat rural et de nombreux petits commerces dans certaines parties du site, menace les surfaces boisées par le grignotage progressif des terres au profit d'un habitat anarchique.

La menace due aux risques d'incendie est également un facteur à prendre en compt. En effet la forêt de Zouara a subi au courant de l'été 1999 un incendie qui a ravagé plus de 50 hectares dont la cause semble être la rupture de certaines lignes électriques.

La présence de plusieurs vestiges archéologiques dont les plus importants sont un ancien port et une quantité non négligeable de vestiges préhistoriques. Ces éléments constituent un patrimoine culturel important qui appuie le caractère spécifique de la zone et son besoin en matière de protection.

La dégradation de la faune présente au sein des dunes et ce essentiellement par:

– Des dommages affectant la structure génétique des populations de talitrides,
– Une paupérisation des arthropodes fouisseurs causée par l'implantation des constructions permanentes ainsi que par la pression occasionnée par les véhicules au niveau de la plage.

La mauvaise exploitation de la plage par les estivants: En effet on remarque que lors des grandes affluences d'été, les baigneurs affichent le plus grand irrespect par rapport au caractère environnemental du site dans la mesure et outre une sur - fréquentation parfois abusive des lieux, cette population se caractérise par des pratiques générant pollution, rejet de déchets et d'objets en matière plastique, dégradation de la végétation…

La présence d'un peuplement ornithologique sur les lieux est également un fait à signaler: En effet la création du plan d'eau du barrage a permis l'installation de certaines espèces ornithologiques plongeuses (du groupe des Anatidés). Ce type de plan d'eau constitue un milieu de refuge pour les oiseaux d'eau lors des périodes de migration: c'est ici l'un des rares points positifs de l'aménagement du barrage.

La fixation des dunes par des structures horizontales peuvent rompre l'équilibre de stabilité de ces dunes mobiles et de remettre ainsi en cause l'équilibre de tout un écosystème.

Le prélèvement de la végétation dans le cadre de l'exploitation de la forêt peut constituer une menace pour les dunes stabilisées, s'il n'est pas bien géré.

La capture anarchique de certaines espèces animales qui risque de rompre l'équilibre des ressources naturelles présent dans la zone d'étude. Notons également que les moyens de capture de ces animaux, essentiellement le piégeage, sont des procédés irrespectueux pour l'environnement du site et peuvent, si aucune mesure n'est prise, en arriver à la destruction de toutes ou parties des populations faunistiques présentes dans la forêt.

L'utilisation des dunes comme terrains de parcours par des ruminants risque de les fragiliser d'avantage.

La convoitise du site pittoresque de Zouara pour l'installation d'activités touristiques dont certaines sont déjà envisagées qui risque de détruire les richesses aujourd'hui reconnues sur le site.

b. *Les aptitudes du site de Zouara a l'amenagement*

Ainsi les sites particulièrement fragiles qui nécessitent une haute protection ont été exclus de toutes forme d'aménagement qui risque de générer une fréquentation et une pression sur le sol.

Il s'agit notamment:

- Des sites renfermant les dunes dont essentiellement celles non consolidées,
- Des sites faisant l'objet de mise en défens,
- Des sites renfermant des vestiges préhistoriques ou archéologiques et même ceux où la présence de vestiges est soupçonnée,
- Des zones exploitées par l'activité agricole dans la mesure où ce ne sont pas nécessairement des sites particulièrement vulnérables mais où il est recommandé de préserver ce type d'occupation,
- Des zones boisées renfermant une végétation précairement établie ou présentant des signes de dégradation ou de mortalité de certaines espèces,
- Des sites littoraux où il est recommandé de préserver la qualité de plage et de l'environnement marin face au boisement,
- Du parcours de l'oued et de ses abords et surtout le site des travaux du barrage,
- De la zone où il y a formation d'une large étendue d'eau provoquée par ces mêmes travaux,
- Du site des travaux de désensablement du débouché de l'oued.

Hormis ces sites, jugés particulièrement vulnérables ou sujets à fortes menaces, les autres parties du territoire de Zouara sont en mesure, sous réserve, de recevoir certains équipements et de supporter certaines activités y compris celles générant une fréquentation humaine pouvant être parfois soutenues.

c. *Les orientations de protection et de valorisation*

Ces mesures sont dressées dans l'objectif de protéger les potentialités écologiques contenues par le site et de garantir le maintien de l'équilibre de cet écosystème vulnérable et de ses différentes ressources.

Ces mesures sont principalement 4 volets:

1. La mise en œuvre de structures de suivi de l'évolution du site; il s'agit de:

- L'établissement de bilans pour évaluer l'évolution des aspects topologiques et topographiques de la forêt; Ces bilans sont susceptibles de suivre d'une manière exacte les mouvements de la dune et d'observer toute modification potentielle,
- L'établissement d'un inventaire, le plus précis possible, ciblant la flore au sein du boisement,
- L'établissement d'un constat relatif aux peuplements faunistiques de la zone boisée,
- L'association de certains experts dans les actions de suivi du biotope du site boisé et de conservation des ressources naturelles reconnues dans le périmètre d'étude,
- Le constat de toute forme de dégradation pouvant affecter l'aspect naturel et environnemental,
- L'établissement d'inventaires concernant l'aspect floristique et la qualité de l'eau du milieu marin; Cette action permettra essentiellement de mesurer l'évolution des herbiers en terme de surface occupée et d'inventorier les espèces végétales,
- Le répertoriage systématique des différents peuplements végétaux au sein de la forêt ainsi que la valorisation des pieds vétérans des espèces existantes,
- La reconnaissance de la valeur scientifique de la forêt de Zouara,
- L'établissement de bilans concernant la faune marine; Cet exercice sera en mesu-

re de répertorier les différentes espèces présentes en mer et cela aussi bien quantitativement que qualitativement,
– La mise en place d'un système de contrôle des dunes qui constituent le support terrestre de la forêt,
– Le lancement d'une étude ponctuelle dont l'objet serait l'examen du système dunaire de la forêt de Zouara; Cette étude aura pour objectifs l'analyse des conditions actuelles, l'évaluation des impacts subis par ce système et enfin rechercher les solutions les plus adéquates pour remédier aux éventuelles dégradations dont ont pu faire l'objet les dunes,
– Le lancement d'une étude ponctuelle ciblant l'élément du barrage pour identifier:
  - l'état du site avant les travaux,
  - l'envergure et les conditions dans lesquelles se sont fait ces travaux,
  - les impacts exacts subis par le site suite à l'exécution des travaux,
  - la projection des impacts encore prévisibles risquant d'affecter l'écosystème,
  - les solutions auxquelles on peut encore avoir recours pour stopper ou réduire certains impacts négatifs et pour palier à certaines mutations de l'écosystème,
– L'élaboration d'une étude d'impact sur l'environnement, la plus exhaustive et la plus complète possible, de la réalisation du projet touristique préconisé par le SDAZS.

2. La mise en œuvre d'actions de protection:
– La mise en place d'un contrôle plus rigoureux de la forêt et le renforcement du gardiennage,
– La défense absolue de tout rejet de détritus et de déchets non biodégradables risquant de polluer l'environnement terrestre et/ou marin de la forêt de Zouara,
– La mise en place d'un contrôle rigoureux de la pratique de la plage par les estivants et ce particulièrement au courant de la saison d'été,
– La mise en place de procédures d'éclaircissement de la forêt pour empêcher l'eutrophisation des espèces végétales et pour parer à l'expansion d'un éventuel incendie,
– L'aménagement d'une ceinture coupe feu le long du passage des principales lignes électriques et voies de circulation dans l'aire de la forêt,
– Le nettoyage et l'entretien réguliers et assidus des surfaces boisées,
– L'organisation de campagnes de nettoyage de la plage,
– L'entretien de la totalité du site (forêt, plage et dunes) à l'aide de moyens manuels en veillant à préserver le matériel organique et sans avoir recours à des procédés mécanisés,
– L'aménagement sur le site de la plage de collecteurs de déchets en nombre suffisant,
– L'interdiction la plus stricte de certaines pratiques employées par les estivants tel que nettoyage de vaisselle en mer, arrachage de branches…,
– L'interdiction de livrer à eux-mêmes les ruminants au sein du périmètre de la forêt,
– L'interdiction de l'occupation permanente ou d'une forte pression au niveau des dunes, essentiellement les premières d'entre elles et les non encore stabilisées,
– La réduction de l'exploitation des voies et des chemins menant à la plage et traversant la forêt,
– L'aménagement d'un minimum d'accès à la plage en balisant des cheminements choisis,
– La réduction au maximum de la pression générée par le passage et le stationnement des véhicules au sein de la forêt et aux abords de la plage,

- L'interdiction de l'accès à la forêt d'engins lourds,
- L'accord d'un intérêt tout à fait particulier au contexte des dunes en défendant toute action susceptible de générer une perturbation de leur maintien et de leur équilibre précaire,
- La réglementation de la production urbaine anarchique relevée dans le périmètre d'étude et dans son environnement immédiat; Il est recommandé à ce niveau de faire établir un document réglementant les territoires et les conditions de constructibilité de la zone,
- La prise des mesures nécessaires pour empêcher l'occupation et la pratique de la totalité de la forêt quelques soient les orientations décidées par le plan de gestion de la zone,
- L'interdiction sur le sol de la forêt d'intervention lourdes capables de transformer les conditions topographiques et topologiques du sol ou d'affecter le maintien des dunes,
- L'interdiction d'implanter des structures construites importantes (en terme de masses et d'étendues) sur le sol de la forêt, sur les dunes ou sur la plage,
- L'interdiction de réaliser tout type d'ouvrage en mer risquant de perturber l'écosystème marin; Il est entendu par cela l'aménagement de quais en dur, de barrages, de digues…,
- Interdire tout type de projet générant grande affluence et occupation importante du site, essentiellement les projets hôteliers autres que ceux prévus par le SDAZS de la zone sensible de Tabarka – Zouara.

3. La mise en œuvre d'actions de sensibilisation:

- La sensibilisation, à l'aide de recommandations et d'affiches, de la population locale et des occupants saisonniers au caractère vulnérable du site,
- La sensibilisation de la population locale à éviter le prélèvement de certaines espèces végétales.

4. La mise en œuvre d'actions de valorisation et d'aménagement:

- La valorisation du site de la source comme un point d'intérêt de la zone sensible et intégrer ce point dans une dynamique éventuelle à concevoir pour la zone,
- La valorisation des sites et des vestiges préhistoriques et archéologiques relevés sur place ou dans les environs du périmètre d'étude,
- La préservation des sites historiques et anciens en aménagement des aires de protection tout en y interdisant toute fréquentation et toute installation ponctuelle ou permanente,
- Le recours à un tourisme de type "écologique" au sein de la forêt; Cet éco-tourisme sera en mesure de minimiser les impacts négatifs pouvant être encourus par la zone suite à une installation hôtelière sur son territoire; D'autre part la pratique d'un tourisme écologique est susceptible de valoriser d'avantage la zone de Zouara et de contribuer à sa protection,
- L'option de recourir, dans la réalisation de constructions en dur:
  - à des structures légères n'occasionnant que le minimum de nuisances au site de la forêt et à celui des dunes,
  - à des choix structurels ne nécessitant pas de fondations profondes ni des travaux trop lourds,
  - à des solutions d'échelle et de traitement (entre autres séquences de façades)

s'intégrant dans la dimension de la forêt et ne rompant pas avec la qualité du paysage de la zone,

– La sélection de matériaux adaptés aux particularités paysagères du site et l'emploi de l'élément végétal dans la réalisation d'unités construites au sein du périmètre de la zone d'étude.

d. *Le projet d'amenagement*

1. Options d'aménagement

Il s'agira de programmer au sein du périmètre d'étude un certain nombre d'activités contenues dans des aménagements particuliers de manière à:

– Induire une "clientèle" ayant une conscience de la sensibilité environnementale de la forêt,
– Réglementer les conditions selon lesquelles se pratiquent toutes ou parties de la zone,
– Dynamiser un contexte culturel déjà présent ou projeté,
– Eviter à l'aspect paysager de la forêt toute tentative ultérieure de dégradation,
– Garantir au site les meilleures conditions de maintien de son équilibre écologique.

2. Programme d'aménagement (Fig. 5.1)

Dans le cadre des options d'aménagement cité ci-dessus, on propose sur le territoire de la forêt les activités suivantes:

La projection d'une unique zone de tourisme écologique telle que programmée par le schéma d'aménagement de la zone sensible de Tabarka – Zouara. L'amorce de cette zone est distante d'environ 1,2 kilomètres de la plage et de près de 3 kilomètres de l'Oued Zouara et se situe à proximité immédiate de la voie d'accès de la plage de Zouara. La surface réservée à la réalisation de la zone touristique est d'une centaine d'hectares devant accueillir, selon les données du SDAZS, de 1500 à 2000 lits en fonction des densités retenues.

Une structure d'accueil au niveau de l'accès principal à la forêt. Cet aménagement est destiné à la réception des visiteurs ou des estivants allant vers la forêt ou vers la plage et qui seront à cet endroit sensibilisés aux valeurs environnementales et aux raisons de la vulnérabilité du site.

Une aire d'animation à proximité de la structure d'accueil projetée. Il s'agira d'un petit ensemble servant comme première halte aux visiteurs motorisés ayant fait probablement et au préalable d'une longue route. Cette aire d'animation renfermera une cafétéria, un espace de jeux éducatifs pour enfants, ainsi qu'une exposition traitant des ressources écologiques de la zone et certains éléments de l'archéologie présente sur les lieux.

Une zone de relais à proximité de l'accès secondaire à la plage. Cet espace conçu pour la détente du visiteur devra renfermer un petit café où il pourra être consommé boissons et nourriture légère ainsi qu'une aire aménagée destinée à accueillir les pique-niqueurs. L'aire de pique-nique sera équipée du mobilier urbain nécessaire à cette pratique.

Un petit nombre de points buvettes, réparties sur la longueur de la plage. Ces aménagements ponctuels n'auront qu'une petite emprise au sol et seront érigés avec des matériaux légers. La réalisation de ces buvettes ne devra pas être accompagnée de terrasses en dur mais tout au plus de quelques mobiliers permettant aux consommateurs de s'asseoir pour un court moment.

Une série d'abris pour les pêcheurs. Ces petits abris sont à aménager au niveau même de la plage, à mi-chemin entre les deux accès à cette dernière Ces aménagements de petite envergure, sont destinés un minimum de confort et de fonctionnalité pour les pêcheurs du coin. Cette initiative est par ailleurs en mesure de matérialiser un point d'intérêt de la part des visiteurs qui sera susceptible de favoriser d'une part l'implication du pêcheur dans la nouvelle conception du site après aménagement et d'autre part l'implication du visiteur dans la dynamique active de la zone côtière de Zouara (techniques de pêche, variétés des espèces pêchées, …).

Des aires de sport au niveau de la plage. Ce type d'aménagement est imaginé pour proposer des sports nautiques ou de plage nécessitant peu d'équipements et surtout un matériel non polluant, comme par exemple la plongée sous-marine, le pédalo et la planche à voile. De légères structures servant au rangement des équipements seront suffisantes à l'exercice de ces activités. La pratique de ces sports sera mise à la disposition aussi bien des estivants de jour que des résidents des unités hôtelières programmées.

Un petit centre ornithologique doublé d'un mirador au niveau du débouché de l'oued; en effet et compte tenu des conditions particulières offertes par le plan d'eau du barrage, on assiste depuis quelques temps au développement de l'avifaune en ce lieu. Aussi devrait-on profiter de cette opportunité pour offrir aux amateurs de la nature et de l'ornithologie une petite structure leur permettant l'observation de ce peuplement d'oiseaux.

Un léger aménagement ponctuant la source de "Ain Ras el Oued" au sein du territoire de la forêt. Par aménagement léger il n'est nullement sous entendu un monument commémoratif mais une simple signalisation indiquant la présence de la source et ses principales caractéristiques.

Une petite aire d'accueil au niveau de la source précitée. Cette aire d'accueil offrira au visiteur, et particulièrement au randonneur (sur le parcours de santé), une halte de repos où il lui sera possible de consommer entre autre l'eau de la source et de se détendre à l'ombre des arbres. Sur cette aire d'accueil, un mobilier léger sera mis à la disposition du visiteur.

Des ateliers artisanaux qui seront prévus toujours à proximité de la source et de l'aire d'accueil. Ces ateliers au nombre de six ou sept seront réalisés sous forme de tentes et renfermeront des activités artisanales locales comme la confection d'objet en bois ou en peau de brebis, la production, avec des procédés traditionnels, des dérivés du lait, le tissage d'étoffes, la mise en bouteille de l'eau de la source, l'élevage des faisans ou des brebis, la fabrication de couffins …

Des points sanitaires dont la nécessité est due à des conditions de fonctionnalité incontournables. Il est projeté d'aménager deux unités au niveau de chaque accès à la plage.

A côté de ces installations, il est proposé certains aménagements comme:

Une aire de stationnement située au niveau de l'accès principal de la plage. Cette initiative est destinée à éviter l'empiétement des dunes par les véhicules lesquels circulent d'ailleurs d'une manière quelque peu anarchique sur les voies de desserte. Le choix d'éloigner l'aire du parking de la plage est volontaire dans la mesure où les dunes non stabilisées ainsi que la végétation courent ainsi moins de risques de dégradation.

Une zone tampon de maîtrise foncière autour du village d'Oulija dont l'extension urbaine "en tache d'huile" est à l'origine du grignotage progressif de la forêt. En effet et en attendant l'élaboration d'une étude susceptible de délimiter définitivement les conditions du développement urbain du village d'Oulija, il est présentement recommander de créer une frange contrôlée ceinturant le périmètre bâti.

Un circuit de santé à l'intérieur de la forêt prévu pour la promenade et la randonnée. Cette proposition ne devra pas nécessiter des aménagements importants mais seulement quelques travaux légers de déblaiement et une simple signalisation des itinéraires projetés. Ce parcours est conçu pour arpenter l'espace de la forêt sur quelques kilomètres, et rejoindre d'une part la plage et d'autre part la zone touristique programmée.

Des ceintures coupe-feu le long des lignes électriques et des voies principales pour protéger la forêt contre d'éventuels incendies.

Le renforcement de la voie transversale perpendiculaire au trait de côte et dont l'état actuel est jugé "en bon état" tout en conservant sa présente largeur, soit quatre mètres.

L'amélioration de la piste longitudinale qui longe la forêt et mène à l'aéroport de Tabarka. Celle ci est actuellement difficile d'accès et devient totalement impraticable par temps de fortes pluies.

3. Utilisateurs potentiels et conditions de fonctionnement

La zone de Zouara, après aménagement, peut accueillir trois types de "clientèles", à savoir:

- Une "clientèle" composée par les estivants. Ces derniers sont pour la plus grande part motorisés et cherchent essentiellement la plage et éventuellement quelques structures d'accueil et d'animation. Ce type de visiteurs affluent exclusivement entre les mois de mai et d'octobre.
- Une autre "clientèle" formée par les promeneurs et les amateurs de découverte des sites naturels. Cette population est susceptible de fréquenter le site entre les mois de septembre à juin en évitant les mois de juillet et août pendant lesquels la chaleur n'encourage pas la pratique de la forêt.
- Une dernière "clientèle" relative aux locataires de la zone touristique, qui chercheront à découvrir le site en toute saison.

Concernant les deux premiers type de visiteurs, ces derniers accéderont au site part la route de Tabarka, et emprunteront pour la plupart la voie principale d'accès à la plage. C'est pour cette raison qu'il a donc été volontairement choisi de placer à cet endroit l'aire de stationnement où il sera impératif de laisser tout véhicule. En ce lieu, sera aménagée la structure d'accueil où des "orienteurs" ont pour mission de sensibiliser les estivants au caractère fragile du site et d'instruire les randonneurs sur les activités et les circuits proposés.

A partir de ce point chaque type de clientèle est censé emprunter un circuit différent.

Le circuit d'été

Ce circuit intéressera essentiellement les estivants qui chemineront à partir de l'aire de stationnement, la desserte principale jusqu'à arriver à la plage. Sur leur chemin se trouvera l'aire d'animation où il sera possible de profiter du petit café pour se reposer et consommer une boisson, où leurs enfants pourront participer aux jeux proposés en ce lieu et où ils auront l'occasion de découvrir l'aire d'exposition pour une meilleure reconnaissance du site.

Une fois sur la plage, ces baigneurs pourront s'installer librement pour quelques heures où il leur sera possible de s'approvisionner depuis les points buvettes aménagés à cet effet.

Les amateurs de sport trouveront sur place trois petites stations proposant chacune la pratique d'une activité différente: ainsi il sera possible de louer un pédalo pour une promenade en mer, d'emprunter un équipement de planche à voile ou de rejoindre le club de plongée pour se faire initier à ce sport.

Les plus aventureux parmi ces baigneurs pourront longer la côte et découvrir les abris des pêcheurs où il leur sera possible de découvrir la variété halieutique caractérisant la zone.

Rien n'empêchera ce type de visiteurs d'emprunter le parcours de promenade au sein de la forêt, ni d'accéder au centre ornithologique.

Les unités accompagnant l'exploitation de la plage seront disponibles de mai à octobre (compris). Les mois restant, elles seront fermées au public ce qui permettra à la structure de gestion du site de procéder à l'entretien de ces unités (points buvettes, des aires de sport et des points sanitaires).

Le circuit d'hiver

Le circuit d'hiver concerne une population peu intéressée par la plage.

La clientèle relative au circuit d'hiver sera inviter dans un premier temps dans la structure d'accueil pour y recevoir une brève présentation du site. Partant de là cette dernière pourra soit se diriger vers la côte pour profiter de l'aire d'animation et pour visiter le centre ornithologique et accéder au mirador à partir duquel il sera possible d'observer l'avifaune, soit se diriger vers le circuit de santé.

Les randonneurs en question pourront être également accueillis:

– Dans le village artisanal où ils visiteront les ateliers et prendront connaissance des diverses activités proposées et des divers produits disponibles,
– Dans le site de la source et dans l'aire d'accueil qui l'accompagne pour faire une halte,
– Dans la zone de relais où ils pourront se restaurer dans le café snack ou sur l'aire de pique-nique.

Il sera par ailleurs tout à fait permis à ce type de visiteurs d'accéder à toutes les autres activités proposées par le site y compris celles intégrées à la zone touristique.

Les aménagements relatifs aux activités "d'hiver" seront exploités de mars à novembre (inclus). Les mois de janvier et février seront consacrés à la restauration des unités d'accueil. Sont visés ici la structure d'accueil, l'aire d'animation, la zone de relais, le centre ornithologique, l'aire d'accueil et l'aire de stationnement.

Concernant la clientèle de la zone touristique

Celle ci pourra accéder dans les meilleures conditions à la totalité des unités et des aménagements proposés par le présent schéma de gestion et cela selon la saison en cours et l'intérêt personnel du touriste.

Pour ce qui est du fonctionnement de la zone touristique et d'après les dispositions découlant du schéma directeur d'aménagement de la zone de Tabarka-Zouara, en retiendra: "Afin qu'il n'y ait pas d'appropriation de l'espace forestier par des privés, il est recommandé que seul 30% à 40% des terrains de l'ensemble de la zone soit cédés aux privés pour l'aménagement de leurs unités". Les chalets de grand luxe: Il s'agit d'unités de grand luxe implantées dans des terrains de 1 hectare et bénéficiant d'un bon niveau de services (femmes de chambre, repas de grande qualité, grand confort). Leurs capacités ne devraient pas dépasser les 30 lits et leur gestion devra être assurée par un système familial dans un cadre chaleureux et très confortable.

L'hôtellerie de grand luxe est previe pour une clientèle spécifique qui exige un confort, loin des foules et sans contraintes (vestimentaires, de programmation, de restauration etc …). Il s'agit d'unités hôtelières d'une capacité de 100 à 150 lits facilement gérable pour une clientèle exigeante en service et en confort. Seules quatre ou cinq unités de ce type peuvent être programmées dans la zone avec des chambres spacieuses ou des bungalows.

Les aménagements susceptibles d'intéresser le plus la clientèle touristique à savoir, le village artisanal et le parcours de santé, resteront ouverts en permanence. Devant la nécessité d'entreprendre l'entretien annuel de ces aménagements, il sera prévu la durée d'une semaine de fermeture (à définir en fonction de l'affluence des visiteurs potentiels).

Les abris de pêcheurs seront opérationnels les douze mois de l'année.

Par ailleurs il est nécessaire de programmé un gardiennage permanent et vigilant sur toute la zone. Ce gardiennage aura pour entre autre mission à veiller à l'application des interdictions suivantes:

– Le prélèvement de faune ou de flore sur le site,
– La consommation de produits alimentaires ailleurs que sur les espaces prévus à cet effet,
– Le rejet de restes ou de déchets sur le territoire de la forêt ou en mer,
– L'allumage de feux ou l'utilisation de produits inflammables,
– La circulation sur le cordon dunaire.

5.3.2 *Deuxième cas: Le site des Îles Kneiss*

a. *Rappel des facteurs de sensibilité des Îles Kneiss*

Dans un premier temps nous citerons les principales *spécificités écologiques et culturelles* des îles et qui confèrent précisément au lieu son caractère riche et exceptionnel. Ainsi on peut noter:

Une concentration de population ornithologique aussi bien importante que variée, (quelques 300000 oiseaux au moins migrent chaque année à travers le complexe des îles). C'est probablement ici l'aspect le plus riche et le plus exceptionnel qui caractérise les Kneiss (il paraît que l'estran est vraisemblablement le plus important de la Méditerranée).

Une flore marine suffisamment riche consistant essentiellement en la présence d'importantes prairies de cymodocées (sur plusieurs milliers d'hectares) situées le long du littoral et au large des îles.

D'importantes ressources halieutiques en matière de faune qui est à la fois spécifique et particulièrement abondante et diversifiée.

De grandes vasières et de chenaux permettant l'installation de conditions écologiques très variées.

Une grande biodiversité au niveau de la faune terrestre caractérisée essentiellement par une variété d'invertébrés.

Une biodiversité au niveau de la flore terrestre qui n'est pas non plus à négliger (en matière de différentes espèces de plants et une floraison exceptionnelle au printemps).

Une présence de vestiges archéologiques qui mériteraient certainement une meilleure protection et des fouilles plus exhaustives car ils représentent une confirmation de l'intérêt de la zone (sur l'îlot d'el Hjar et sur celui d'el Gharbia, on peut observer des citernes ainsi qu'une quantité d'amphores, sur l'îlot d'el Laboua, on peut voir les restes d'un monastère et d'une petite église, et un peu partout sur les falaises, mises à nu par l'érosion, il y a des vestiges antiques dont un monument funéraire au niveau de l'angle Nord).

Les facteurs de sensibilité des îles sont tout aussi bien représentés par les multiples formes de nuisances faisant pression sur aussi bien l'environnement terrestre que marin, dont voilà ci-dessous les aspects les plus préoccupants:

Une pollution non négligeable par hyperthrophisation, qui est essentiellement due:

– Aux conséquences de l'industrie de transformation des phosphates,
– Au déversement des hydrocarbures.

Un phénomène de destruction des prairies de cymodocées qui sont pourtant l'une des principales richesses du milieu marin et l'un des indices de bonne santé de ce milieu.

Des impacts du raclage des fonds marins par des engins de pêche. Notons que la pêche n'est pas réglementée et que ce genre de pratique, quoique défendue est en mesure, à long terme, de massacrer définitivement la flore marine présente sur les lieux.

Une grande pollution sur les côtes des îles due à la présence de quantités très importantes de matière plastique et cela sous la forme de bouteilles, de sacs, d'emballages…, sans pour autant oublier les boîtes de conserve. Signalons que ce type de pollution est tout à fait non biodégradable.

Une surexploitation des ressources en palourdes mais aussi en crevettes. En effet les habitants des villages côtiers se rendent souvent sur les îles pour y prélever les mollusques qu'ils revendent par la suite pour survivre. Cette situation est en mesure de générer d'importantes conséquences à l'équilibre de ce type de faune sur les lieux, aussi vaut-il mieux, faute d'interdire définitivement cette pratique, au moins de l'éviter pendant quelques mois de l'année.

Une pratique qui est aujourd'hui sévèrement contrôlée et définitivement interdite et qui consiste d'une part à laisser paître les moutons sur l'île et d'autre part à couper la végétation locale pour en extraire de la matière combustible au profit des habitants des villages côtiers.

Un phénomène de massacre des tortues de mer qui sont d'ailleurs le plus généralement dépecées sur place. Cette pratique, outre le fait qu'elle soit illicite, est grandement néfaste pour la présence de ce type de faune près des îles et pour les chances de leur pérennité.

Des agressions déplorées subites par les espèces ornithologiques dont on prélève les œufs. Cette pratique minimise la profusion des espèces et menace même leur présence sur le site, cela à côté du dérangement subi par la totalité des races de nicheurs de la part de l'homme.

Une action érosive dont les principaux indices sont la mise à nu des vestiges archéologiques (essentiellement des citernes) situés aux abords des falaises et qui subissent actuellement un effritement continu.

En considération à toutes ces raisons, qu'elles soient en rapport avec les ressources identifiées sur les îles ou en rapport avec les différentes menaces dont nous avons ci dessus établi l'inventaire, il est reconnu aux Îles Kneiss un degré de sensibilité important et mérité.

En réponse à ce constat, il est nécessaire de définir le plus urgeament possible:

d'une part, certaines mesures conséquentes à cette situation et capables de protéger le site et de lui garantir les conditions favorisant le maintien de son équilibre environnemental et culturel,

et d'autre part, un plan de gestion spatial en mesure de garantir une exploitation raisonnable des potentialités relevées et de définir "un mode de fonctionnement" évitant au mieux toute dégradation potentielle tout en mettant en valeur les différentes richesses retenues par les diagnostics établis.

N'oublions pas enfin que le complexe des zones humides des Îles Kneiss représente non seulement un site clé à l'échelle de toute la Méditerranée occidentale mais également une richesse écologique dont l'importance est jugée internationale.

b. *Les aptitudes du site des Kneiss a l'amenagement*

Il a été reconnu lors des expertises thématiques dont a fait l'objet le site et surtout lors des recommandations qui s'en sont découlées que l***e territoire des îles était tout à fait inapte à recevoir une quelconque implantation ni d'ailleurs une pression humaine fréquente et soutenue.***

Il demeure cependant que les îles ne sont pas un territoire détaché de tout environnement physique mais qu'il doit être considéré par rapport à son contexte géographique, c'est à dire par rapport à la portion de la côte continentale qui lui face. Cette dernière, caractérisée par bien moins de facteurs de vulnérabilité que les îles, est appelée dans ce cas de figure à matérialiser la continuité aussi bien géographique que dynamique des Kneiss. Aussi s'agit-il ici de se reposer sur cette partie du littoral pour concrétiser le contexte actif dans l'aménagement de la zone.

c. *Les orientations de protection et de valorisation*

Sur la base de l'étude diagnostique et l'analyse de l'aptitude du site, il ressort les orientations suivantes:

- Exclure sur le territoire des îles toute éventualité d'aménagements lourds ou d'échelle importante,
- Exclure sur ce même site toute fréquentation démesurée ou continue,
- Envisager certains aménagements, avec réserve, sur l'arrière pays continental,
- Insister sur le respect et les interdictions découlant de l'application du D.P.M. (Domaine Public Maritime) sur cette face continentale,
- Envisager un aménagement qui prenne en compte aussi bien la vulnérabilité de l'archipel des Kneiss que le contexte environnemental de la côte continentale.

d. L*es mesures de protection*

Ces mesures de protection concernent aussi bien le site que les zones ayant une influence directe ou indirecte sur son equilibre. Leurs objectifs est de préserver les potentialités naturelles, culturelles et paysagères révélées par le site et de garantir ainsi la pérennité de cet écosystème îlien fragile et le maintien des différentes ressources qui y sont observées.

Il s'agit essentiellement:

- De protéger la flore terrestre et d'éviter la pratique, aujourd'hui pratiquement abandonnée, de l'arrachage des végétaux; Un inventaire de cette biodiversité naturelle est vivement conseillé,

– D'établir un constat de reconnaissance du contexte faunistique diagnostiqué sur le site d'étude et d'œuvrer pour sa protection; Il est en effet reconnu à travers les expertises établies que l'île est le territoire d'une grande variété d'invertébré,
– D'accorder une attention particulière à la présence de la faune ornithologique relevée sur le site d'étude; En effet cette dernière paraît être la plus importante des richesses naturelles et culturelles diagnostiquées sur le milieu îlien,
– De procéder au suivi des espèces ornithologiques qui peuplent l'île ou qui n'y sont que de passage lors des migrations; Ce suivi se fera essentiellement à travers des constats périodiques et des inventaires destinés à mieux cerner les aspects quantitatifs, qualitatif et comportemental des oiseaux,
– De strictement interdire le ramassage et la destruction des œufs; En effet les îles sont réputées pour être le lieu de reproduction de plusieurs espèces ornithologiques et cela est d'ailleurs l'une des plus grandes spécificité du milieu,
– D'interdire tout type de gêne occasionnée à la population ornithologique en terme de perturbations diverses, de destruction des nids…,
– De protéger les vasières qui non seulement permettent l'installation de conditions particulières écologiquement aussi variées qu'intéressantes mais qui offrent des opportunités d'alimentation pour l'ornithofaune présente sur les Îles Kneiss,
– De prendre les mesures nécessaires pour la protection du contexte floristique marin du milieu dans la mesure où d'une part ce milieu est un indicateur de "bonne santé" de l'écosystème marin et d'autre part, il est sujet à différentes dégradations,
– D'accorder un maximum d'attention à la pollution de l'environnement marin observée sur le site; Cette pollution est d'origine industrielle; A cet effet il est important de:
  - envisager des actions en mesure d'endiguer l'impact négatif de la dispersion du phosphogypse en mer à partir des terrils,
  - veiller à "l'opérationnalité" des moyens de lutte contre un possible déversement accidentel d'hydrocarbures,
– De prendre les mesures qui s'imposent pour empêcher tout acte susceptible de dégrader les *prairies de cymodocées* qui peuplent le milieu marin de la zone,
– D'interdire les actions en mesure de dégrader les fonds marins particulièrement par le raclage de ces derniers,
– De prohiber certaines techniques de pêche à l'origine de la dégradation des fonds marins; A cet effet il est conseillé de réglementer la pêche et d'encourager l'emploi des techniques de pêche traditionnelles,
– De mettre en œuvre les procédures nécessaires pour le suivi de la qualité de l'eau,
– De protéger la faune aquatique (poissons, crustacés et mollusques); L'établissement d'inventaires quantitatifs et qualitatifs serait un moyen efficace pour pouvoir cerner le potentiel en aquafaune,
– D'accorder une attention particulière au phénomène de la surexploitation des ressources en palourdes et en crevettes dans la mesure où ces dernières sont systématiquement récupérées par les pêcheurs artisanaux en provenance de la côte continentale,
– D'interdire le plus strictement possible le massacre des tortues capturées et le plus souvent dépecées sur place,
– D'accorder une attention au phénomène d'érosion observé sur le site; A ce titre il est recommandé de lancer une étude spécifique dont les objectifs seraient de:

  - evaluer les effets actuels de l'érosion,
  - evaluer ce même phénomène sur une période ultérieure établie en fixant des repères précis,
  - rechercher et mettre en œuvre des solutions susceptibles de stopper, voire de diminuer les effets de l'érosion sur le site d'étude,
- De procéder à un suivi rigoureux de la qualité des apports des affluents continentaux,
- De préserver le site et ses environs des effets de la pollution d'origine humaine; En effet l'observation la plus flagrante pouvant être faite sur le site est malheureusement celle relative aux amas de déchets non dégradables,
- De procéder au ramassage fréquent et périodique de ce type de déchets aussi bien depuis le continent que sur les îles,
- De renforcer les mesures de gardiennage et de surveillance qui sont déjà présentes sur les lieux,
- De protéger le patrimoine archéologique relevé sur le site des Kneiss; Pour cela il est nécessaire:
  - d'encourager les actions de fouilles ainsi que les travaux des chercheurs et des archéologues,
  - de procéder à des missions de reconnaissance destinées à établir des inventaires précis relevant le contenu de ce patrimoine historique,
  - d'établir des aires de protection des sites reconnus,
  - d'interdire toute pratique de ces sites à d'autres visiteurs que les archéologues et les chercheurs en matière d'archéologie,
- De veiller, à court terme, au respect de ces sites (piétinement, prélèvement de matériaux…) par les pêcheurs et autres visiteurs non avertis,
- D'interdire catégoriquement tout accès aux petits îlots; Cette interdiction peut toutefois être occasionnellement levée dans le cas de campagnes d'inventaire ou de visites de chercheurs et/ou de spécialistes,
- De contrôler le plus efficacement possible la fréquentation de l'île principale et de veiller à éviter toute sur-occupation même occasionnelle de ce territoire,
- D'interdire au mieux la fréquentation des lieux pendant la période de reproduction des oiseaux,
- D'interdire, sur le territoire des îles, toute construction ou édifice:
  - clos et réalisé en dur,
  - dont les matériaux, l'emprise et la hauteur seraient en contradiction avec les caractéristiques paysagères du lieu,
  - en mesure de bouleverser un tant soit peu les caractéristiques et la nature du sol iléen.

e. *Le projet d'amenagement*

Dans la mesure où il a pu être dégagé lors de l'établissement des mesures de protection les actions à envisager pour la protection du site et la préservation de ses ressources, la partie suivante sera consacrée à la mise au point du plan de gestion en terme d'aménagement.

1. La proposition d'aménagement

Il va de soi que les aménagements qui concerneront le territoire des îles seront peu importants dans la mesure où le caractère fragile de l'écosystème ne permet que très peu, voire pas du tout d'interventions sur le site et que dans ce cadre précis c'est bien entendu en conséquence de cet équilibre précaire qu'il est nécessaire d'agir.

En contre partie, c'est sur le sol continental, face à l'archipel, que les possibilités d'aménagement sont permises et que c'est précisément ce territoire qui sera destiné à matérialiser les conditions écologiques particulières des îles, à présenter les potentiels et les richesses en ressources contenues par l'environnement des Kneiss et enfin à concrétiser la fonction culturelle et ludique qu'il s'agit d'insuffler à la zone.

1. Les propositions d'aménagement sur le territoire des îles (Fig. 5.2)

Outre la très haute protection dont devra faire l'objet le territoire de l'archipel et ce en terme de préservation des ressources naturelles et écologiques relevées et en actions destinées à éviter toute dégradation de ces ressources (voir les mesures de protection), il est proposé sur le site des Kneiss les actions suivantes:

Interdire l'accès aux petits îlots (el Gharbia, el Laboua et el Hajar) par toute saison et par tout type de fréquentation, exception faite aux opérations d'inventaires relevant du suivi de la zone et éventuellement aux chercheurs avec réserve de l'effectif présent sur terrain, des travaux à accomplir et de la durée de leur intervention.

Prévoir sur l'île principale, certains aménagements légers en mesure de s'inscrire dans une logique d'accueil d'une petite fréquentation "avertie" et de faciliter l'embarquement et le débarquement depuis ce site. Ces équipements seront situés sur Dzirat el Bassila et sont essentiellement:

Un petit embarcadère devant nécessairement être en structure légère, cette installation est en mesure de réglementer et de faciliter l'abordage de l'île,

Un abri couvert mais ouvert destiné à recevoir certaines fonctions de première nécessité; L'aménagement en question ne devra en aucun cas perturber la nature de la topographie du site ni aller à l'encontre des caractéristiques paysagères des îles,

Un aménagement d'un circuit de promenade et de découverte de l'île; Ce circuit ne devra pas nécessiter d'aménagement lourd mais devra se suffire d'une simple signalisation indiquant les cheminements prévus à cet effet.

2. Les propositions d'aménagement sur le territoire continental (Fig. 5.3)

Au vu de la grande sensibilité et le peu de disposition à toute pression dont fait preuve l'archipel des Kneiss, c'est la face continentale qui se chargera de jouer le rôle de continuité au territoire îlien dans les actions de programmation d'un site d'accueil. Aussi s'agira-t-il de prévoir le plus gros de l'aménagement sur cette côte continentale, plus précisément sur le site dénommé Zaboussa, qui malgré la présence de plusieurs surfaces humides (Sebkhas), est toutefois en mesure d'accepter l'installation de quelques unités fonctionnelles destinées à accueillir les visiteurs du site et les randonneurs éventuels de l'Ile d'el Bessila.

Ces installations doivent s'inscrire dans un cadre:

- de valorisation des ressources paysagères de la zone,
- de moyens de reconnaissance du site fragile de l'archipel,
- de production d'aires de détente pour le visiteur,
- d'intégration du site par rapport à l'arrière pays continental,
- de production d'un cadre culturel mettant en relief la richesse de la zone.

Pour répondre à ce type d'impératifs, il s'agit d'imaginer certaines fonctions qui sont en mesure de drainer une foule modérée, quelque peu consciente du cadre particulier de la zone, de produire des activités répondant aux attentes de cette clientèle, de dynamiser par là le contexte culturel du site et surtout de respecter la vulnérabilité environnementale des lieux.

On propose sur le site de Zaboussa l'aménagement d'un petit parc d'environ une cinquantaine d'hectares où il pourra être développé les activités suivantes:

Une structure d'accueil pour recevoir, sensibiliser et orienter le visiteur désireux d'explorer la zone et/ou se rendre sur l'île d'el Bessila.

Une aire détente en mesure d'offrir au visiteur une halte de repos dans un cadre approprié en relation avec les caractéristiques du site. Cette aire comprendra une petite unité de consommation alimentaire, un espace de jeux pour enfants, un mobilier pour les amateurs du pique-nique…

Un mirador, en matériaux légers, suffisamment élevé, aménagé pour répondre aux visiteurs voulant dans un premier temps observer depuis le site de Zaboussa, l'ensemble des Îles Kneiss en terme de paysage et de population ornithofaune.

Un petit musée racontant l'historique des îles et renfermant certains vestiges archéologiques locaux. Cet aménagement est proposé pour d'une part compenser l'impossibilité de la visite de l'îlot d'el Laboua où se trouvent les ruines du Monastère de Saint Fulgence datant de la période du Vème - début du VIème siècle, et d'autre part pour mettre en valeur le patrimoine archéologique se trouvant aussi bien sur le territoire des quatre îles que sur les territoires continentaux d'en face.

Un musée consacré à la flore et surtout à l'ornithologie. En effet, il a été unanimement reconnu que l'une des valeurs écologiques les plus importantes sur le site des Kneiss était l'effectif tout autant que la variété des espèces d'oiseaux peuplant l'archipel ou en faisant une halte lors des migrations. Pour cette raison il est proposé dans ce cadre l'aménagement d'un local informant le visiteur sur les caractéristiques de cette population, les variétés présentes ainsi que les particularités du milieu insulaire en terme de végétation et de paysage.

Un petit centre ouvert essentiellement à la population locale dans le but de la sensibiliser au cadre environnemental des lieux mais aussi d'offrir l'écoute et l'aide nécessaire aux pêcheurs et aux ramasseurs de mollusques (activités désormais à réglementer).

A côté de ces activités, il est proposé certains aménagements comme:

Une aire de stationnement destinée à accueillir les véhicules motorisés des visiteurs du site ainsi que les groupes,

Un quai permettant l'abordage des embarcations et leur stationnement entre chaque navette,

Un circuit de promenade pédestre distribuant essentiellement les sites littoraux et permettant l'observation de l'archipel et sa population ornithologique depuis la terre ferme,

Une liaison viaire, sans matériaux rigides, reliant le village de Hachichina au site côtier de Zaboussa. La voie à aménager suivra dans un premier temps la trace de la piste existante sur la frange Ouest de Zaboussa puis aura à rejoindre le site proposé à l'aménagement et ce jusqu'au abords du littoral au Nord-Est d'el Guettaia.

Une dernière proposition viendra compléter le programme, il s'agit de l'organisation d'un ***circuit de découverte du site par voie de mer.*** Cette activité aura comme support des embarcations destinées à cet effet qui quitteront l'embarcadère situé à Zaboussa pour longer les petits îlots et rejoindre Dziret el Bessila en y accostant ou en la contournant, pour revenir par la suite au point de départ.

Enfin, rappelons que dans le cadre de la proposition d'aménagement et de gestion du site des Kneiss, les mesures de protection développées plus haut restent non seulement d'actualité mais résument dans leur contenu les actions essentielles à entreprendre pour mettre au point un plan de gestion cohérent et un aménagement compatible avec le caractère de la zone; Aussi il s'agit de garder en mémoire les impératifs de préservation du milieu et de mise en valeur des ressources qui restent les actes les plus essentiels et les plus urgents à mettre en œuvre dans la politique de gestion des Îles Kneiss.

3. Utilisateurs potentiels et conditions de fonctionnement

Le parc est destiné à recevoir aussi bien un public averti (amateur d'ornithologie ou d'archéologie…) qu'une population profane venant sur le site pour y trouver le repos et la détente et profiter des activités culturelles proposées pour éventuellement s'instruire sur certains sujets. Le flux des visiteurs rejoindra le site de Zaboussa depuis le village de Hachichina donc depuis la Route Nationale 1 et sur une distance de presque huit kilomètres à vol d'oiseau. La distance réelle à parcourir par voie carrossable est de l'ordre de 10,5 kilomètres.

A l'entrée de la zone aménagée se situe l'aire de stationnement et l'unité d'accueil des visiteurs: c'est à partir de ce point d'accueil qu'il s'agira de renseigner le visiteur sur la nature des activités offertes aussi bien sur la zone continentale que sur le territoire des Kneiss ainsi que sur les procédés d'exploitation établis par le présent plan de gestion.

Plusieurs circuits sont proposés au visiteur:

Le premier parcours se développe sur la partie continentale de la zone. Il s'agira d'emprunter le circuit de promenade en profitant des points d'animation aménagés. Le premier de ces points est l'aire de détente qui comprendra une cafétéria offrant à ceux qui le désirent l'opportunité de consommer une boisson ou un aliment. Il est bien entendu hors de question que cette activité ne se substitue à celle d'un restaurant nécessitant un approvisionnement important et certaines dépendances telles que cuisines etc.

Une terrasse accompagnera la cafétéria et permettra aux visiteurs de s'installer en plein air pour profiter du cadre offert par l'aménagement projeté. Un mobilier urbain viendra agrémenter cette terrasse: il est proposé dans ce contexte de prévoir des chaises et des tables en bois et étoffe en essayant d'éviter le mobilier en matière plastique.

L'aire de détente comprendra un espace de loisirs pour enfants où il sera aménagé des jeux de plein air ainsi que des activités éducatives ayant pour principal thème la protection de l'environnement et la sensibilisation au caractère vulnérable de l'archipel et aux ressources ornithologiques.

Plus loin se trouvera le musée de l'archéologie dont les espaces seront employés à l'exposition des vestiges archéologiques récupérés sur le milieu continental où sur les territoires des Îles Kneiss.

A côté de l'exposition, l'espace du musée s'appuiera sur des ouvrages écrits et des affiches pour relater l'historique des îles, leur occupation par les moines… Le musée en question pourra renfermer des maquettes reprenant par exemple le Monastère de Saint Fulgence.

Un petit espace de documentation pourra accompagner l'activité d'exposition. Il pourra être mis à la disposition des visiteurs des ouvrages sur l'histoire de la zone ou de sites voisins ou encore des travaux de chercheurs ayant opéré sur le périmètre.

Après avoir visité, pour ceux que cela intéressera, le petit centre destiné à la population locale, le parcours débouchera sur le musée de l'ornithologie, de la faune et de la flore locale. Ce musée racontera par voie d'affiches, de photos, d'illustrations et de visites guidées la richesse exceptionnelle des Kneiss en matière d'ornithologie et renseignera le visiteur sur la végétation et les invertébrés caractérisant la zone. Des maquettes résumant les circuits de migration des oiseaux pourront enrichir la visite.

Parmi les activités proposées par le musée de l'ornithologie, il y aura celle qui préparera le promeneur à la visite du mirador.

Ce mirador est la dernière étape du circuit; Il offrira aux intéressés la découverte, à l'œil nu ou à travers des moyens installés sur place comme des jumelles ou des longues vues, d'explorer le site des Kneiss et d'en contempler la population ornithologique qui fait sa célébrité. Une personne qualifiée devra occuper les lieux du mirador et aura pour fonction de renseigner le visiteur sur les points d'intérêts offerts par le paysage et sur les espèces et les caractéristiques des oiseaux qui pourront être observés depuis les paliers du mirador.

Le parcours finira par conduire à l'embarcadère.

Le site aménagé de Zaboussa pourra fonctionner neuf mois sur douze dans la mesure où les conditions climatiques seront vraisemblablement inadéquates aux activités proposées au courant des mois de décembre, de janvier et de février.

Durant les mois d'accueil, le parc pourra fonctionner de 9 heures du matin jusqu'à la tombée de la nuit.

Il sera défendu à chaque visiteur de pratiquer des actes allant à l'encontre des impératifs de protection de la zone établis précédemment.

Le deuxième circuit prend justement son départ depuis cet embarcadère.

L'activité qui y est proposé est une randonnée par voie de mer permettant de visiter à distance le complexe des Îles Kneiss et d'en observer le paysage.

Cette activité se fera grâce à des embarcations prévues à cet effet.

Les visiteurs intéressés par ce type de loisirs seront accompagnés dans cette activité par un guide qui les renseignera sur les points d'intérêt qu'ils rencontreront et sur les sites qu'ils observeront.

Le circuit proposé partira depuis l'embarcadère prévu à Zaboussa puis s'orientera vers le Sud jusqu'à l'îlot d'el Gharbia qu'il contournera pour longer les côtes orientales de Dziret el Laboua et de Dziret el Hajar. Par la suite l'embarcation approchera Dziret el Bessila par l'Est et la contournera au Nord, puis s'orientera à vers le Sud pour longer à nouveau les îlots sur l'autre versant et retourner finalement à l'embarcadère de Zaboussa.

Ce circuit devra durer en moyenne quatre heures et pourra être réalisé 2 à 4 fois par jour selon affluence et succès de la randonnée.

Un effectif de trente personnes est à prévoir lors de chaque voyage.

L'activité en question pourra se dérouler à partir du mois d'avril et jusqu'au mois d'octobre compris (sept mois sur l'année).

Le troisième circuit est identiquement le même que le précédent sauf qu'il offrira à certains, qui le désirent, de débarquer momentanément sur Dziret el Bessila.

La seule activité permise sur el Bessila est la randonnée sur l'itinéraire apprêté à cet effet. Le circuit en question se développe sur environ 5 kilomètres et permet l'exploration de la partie centrale de l'île et de la zone humide qui l'occupe.

En milieu de circuit, le randonneur peut faire une halte sous un abri. Cet aménagement n'est ni destiné à la détente ni à la consommation alimentaire, il a pour seul but d'offrir un peu d'ombre, un siège et de l'eau, ou en cas de nécessité un soin urgent.

Les visiteurs intéressés par ce circuit pourront être déposés sur l'île d'el Bessila par l'embarcation qui assure le circuit de la randonnée par voie de mer être récupérés par le voyage suivant.

On retiendra que la durée de la randonnée sur l'île sera de l'ordre de quatre heures.

La visite de l'île ne pourra se faire que du mois d'avril à celui d'octobre et sera strictement interdite pendant la période de reproduction des oiseaux.

Seuls dix personnes au maximum pourront se trouver sur l'île simultanément.

La visite d'el Bessila doit nécessairement se faire en présence d'un guide spécialisé.

Il sera interdit aux visiteurs d'el Bessila:

- Le prélèvement de faune ou de flore sur le site de l'île,
- La consommation de produits alimentaires et/ou le rejet de restes ou de déchets in situ,
- La dégradation du patrimoine naturel se trouvant sur l'île,
- La circulation sur le territoire ailleurs que le circuit prévu à cet effet,
- La perturbation des oiseaux (ramassage d'œufs, destruction de nids, pourchasse…).

5.3.3 *Conclusion*

Les approches adoptées pour la proposition d'aménagement des deux sites sensibles de la forêt de Zouara et celui des îles Kneiss restent similaires bien qu'il s'agisse de problématiques différentes. Forêt littorale de fixation de dunes et espaces insulaires. En effet, la collaboration de plusieurs experts avec chacun son analyse et son approche particulière a permis de confronter les idées et de fixer les priorités pour la protection et la valorisation de ces sites dans une perspective de développement durable.

Ainsi, les aménagements projetés répondent nécessairement aux objectifs tracés:

- Valoriser les spécificités paysagères des lieux,
- Produire les moyens permettant la reconnaissance du caractère fragile de la zone,
- Produire des aires de détente pour le visiteur,
- Réaliser un cadre culturel susceptible de valoriser le site de la forêt et des espaces insulaires sensibles.

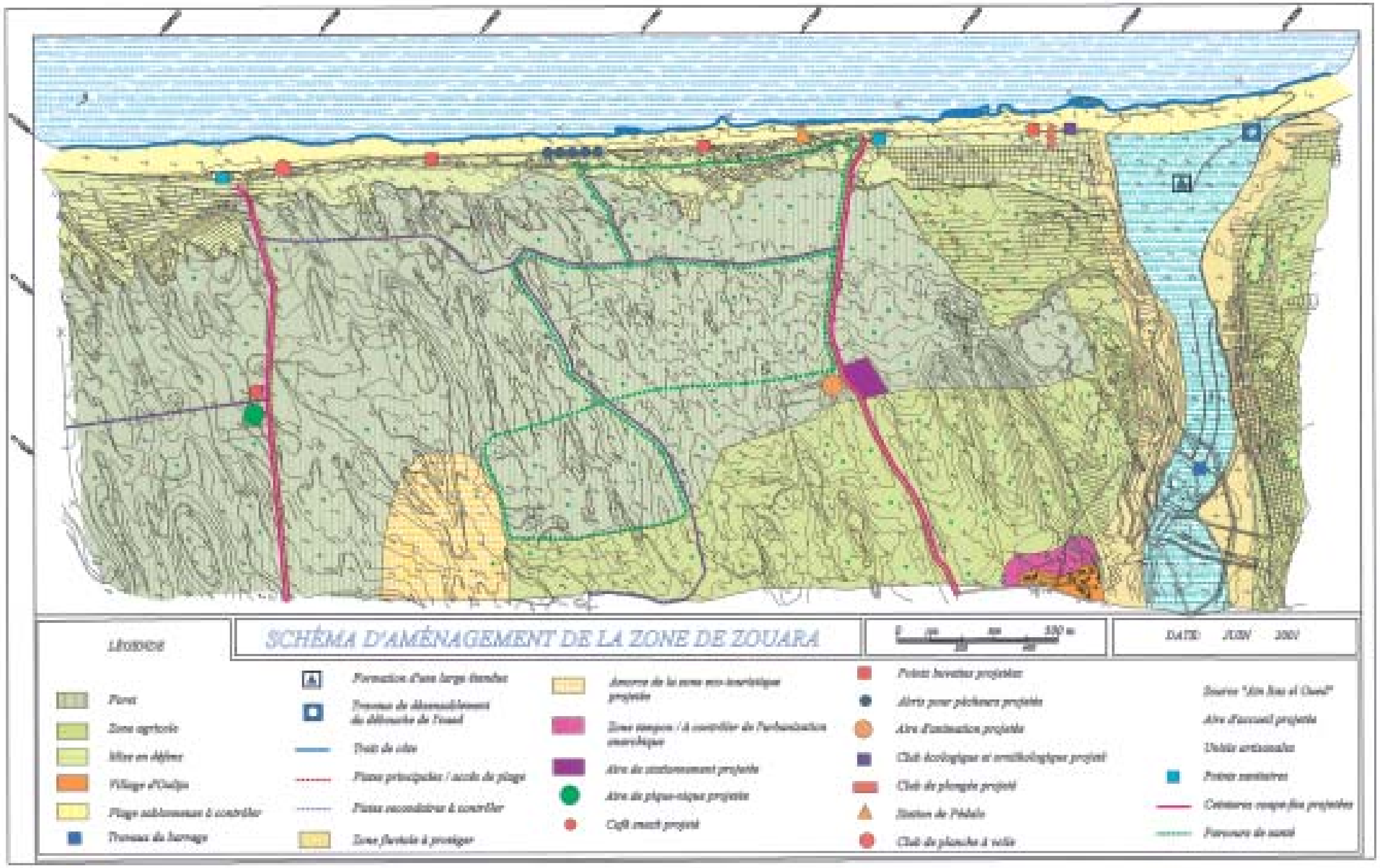

Fig. 5.1 *Schéma d'aménagement de la zone de Zouara*

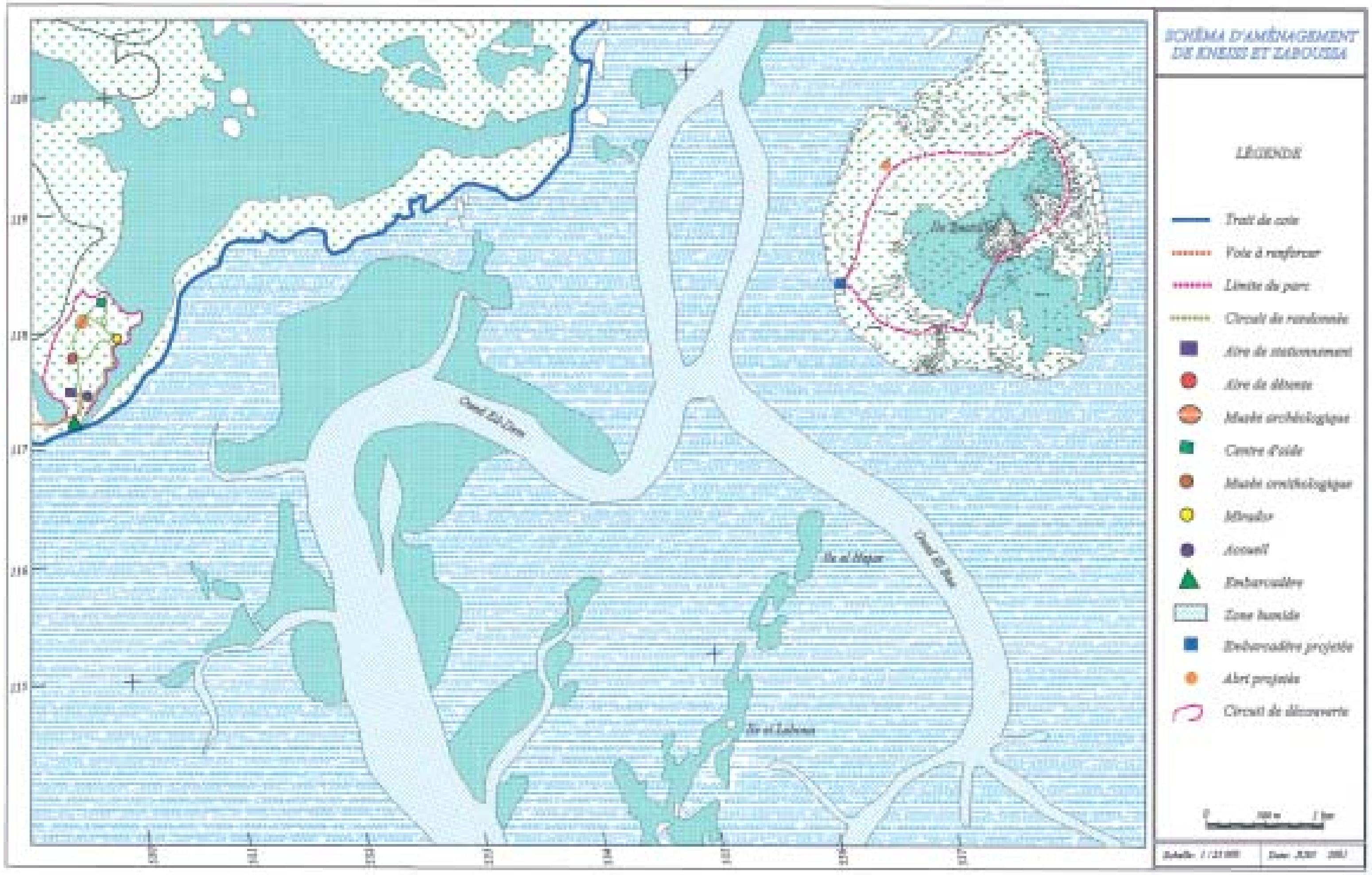

Fig. 5.2 *Schéma d'aménagement de Kneiss et Zaboussa*

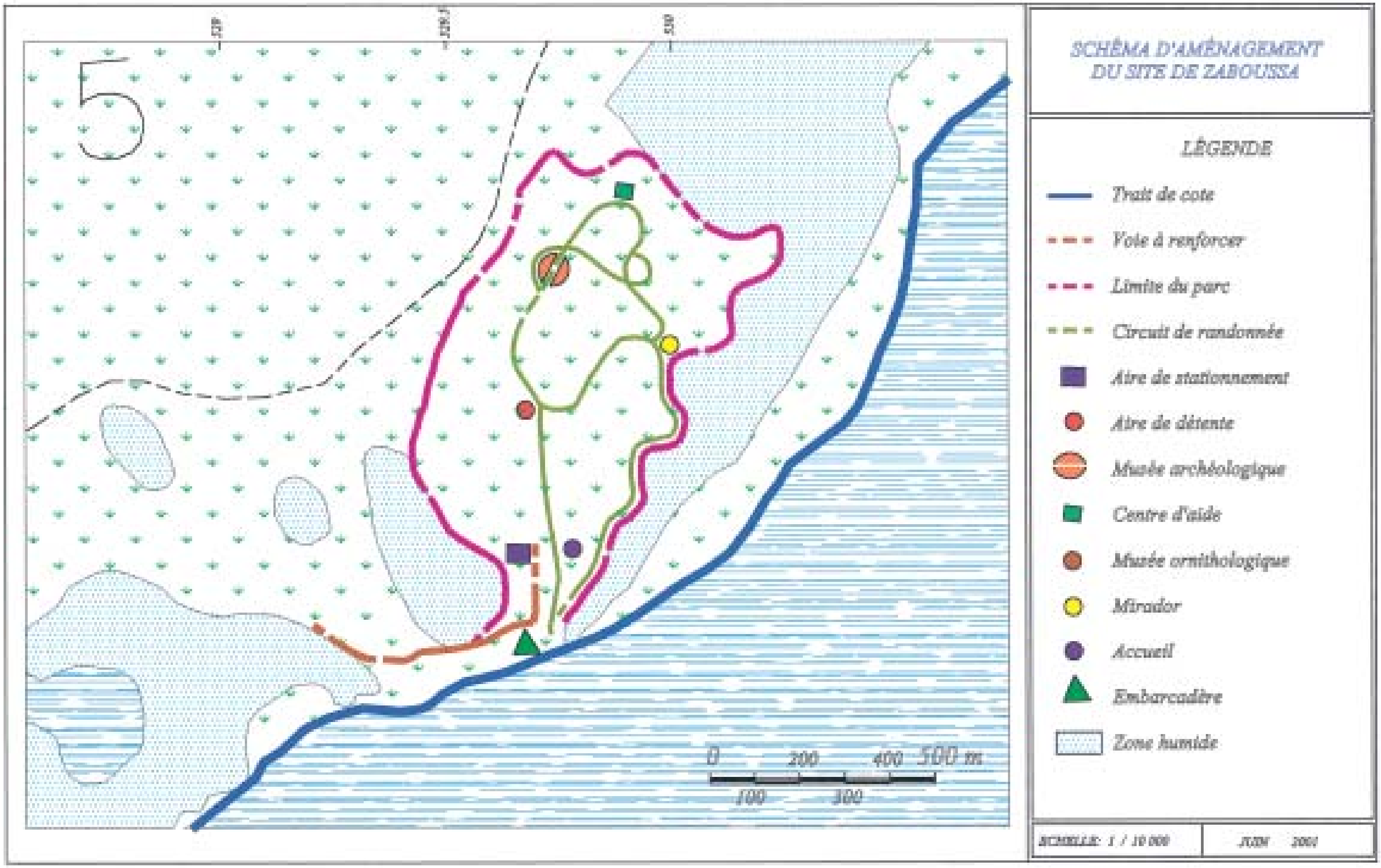

FIG. 5.3 *Schéma d'aménagement de site de Zaboussa*

chapter 6
integration in monitoring and management

Alison Caffyn and Guy Jobbins

This manual has demonstrated the great diversity in Mediterranean sandy and low coasts. It has identified the wide range of threats which these sensitive environments face and the many challenges which face managers. The case study sites studied during the MECO project have demonstrated this diversity in practice.

The project has also demonstrated the diversity of scientific disciplines and research methodologies which can be used to study coastal environments. Managers will have to choose which methods are most appropriate for their sites but the importance of taking a broad approach incorporating a range of indicators has been shown.

From the perspective of management the two most salient facts about ecosystems are their unpredictability, and their 'openness'. Small changes in nutrient input, sediment flow or salinity can have disproportionate effects on productivity, species richness and composition, for example, and changes in ecosystems can be very rapid and difficult to reverse. Often the source of such changes can be outside the area of immediate management, as in downstream effects of dam construction or the loss of breeding habitat for migratory fish stocks. In this sense ecosystems tend to be 'open' with respect to human spatial boundaries, *e.g.* national borders.

When the interactions between human and natural systems are considered, the management problems arising from these two facts are multiplied. Not only are ecosystems 'open' with respect to divisions of the human economy, such as between tourism and agriculture, but market forces on a potentially global scale begin to effect the decisions of resource users. This was shown to be the case at Kneiss, where fishers' increased access to an international market in Sfax has contributed to the decline of local fish stocks. Unpredictability is also increased, as it is not always clear how resource users or the ecosystem itself will respond to management intervention. New laws, regulations and management interventions sometimes result in unforeseen consequences that may be problematic. This is usually what happens when decisions are made on the basis of incomplete analysis, and interventions focus on tackling symptoms rather than causes.

Successful management approaches recognise the complexity of the task facing them. The site needs to be considered in its wider spatial, bio-physical, and socio-economic context in multidisciplinary studies that include analyses of previous management strategies. Management policies, plans and actions need to be co-ordinated both horizontally and vertically, but managers must recognise that resource users are the day-to-day managers of resources; the effectiveness of regulations and policies depends upon whether resource users decide to comply with them. The state should attempt to engage with stakeholders at a level that goes beyond simply informing towards building consensus. We are proposing a more consensual, inclusive approach. We feel it is essential that both research and management address this wider context if they are to be successful.

Finally, plans and decision-making processes need to reflect the unpredictability of the system they attempt to govern. Plans should be flexible, and related to the constant monitoring of indicators.

The key to effective monitoring is to identify the important issues and threats at each site and to then choose a range of appropriate indicators of all sectors. Managers should try to integrate the aims and objectives, the monitoring systems, the decision making process and the management strategies which result. Successful integration helps avoid misunderstandings, conflicts or duplication of effort. It also helps increase efficiency and effectiveness of planning and management actions.

The following check list is presented as a summary of key points made within the manual. It will inevitably not be possible to achieve all points in most locations but we hope it will be helpful for managers to assist in the development, implementation and evaluation of their strategies.

Integration of aims and objectives
- adoption of clear aims and objectives, understood by all stakeholders,
- develop a shared vision which identifies genuine issues and real needs,
- promote consensus through early involvement of all stakeholders,
- seek sustainable use and development of the area.

Integration of monitoring systems
- analyses and assessments which cut across scientific disciplines,
- identify baseline information as far as possible,
- monitoring which includes applied research components,
- provide reliable and necessary information available to all stakeholders.

Integration in decision making, planning and management of beach and coastal areas
- the horizontal integration of separate economic sectors and the associated units of government which significantly influence the planning and management of coastal resources and environments,
- the vertical integration of all levels of government and non-governmental organisations (local, regional, national and international),
- a planning and management perspective which combines land use and sea use processes,
- a programme which includes education for all stakeholders - local people, visitors and managers,
- the active involvement of all stakeholders,
- regular monitoring and evaluation of the overall process.

We hope this manual has contributed to develop better understanding and co-operation between scientists and managers. Scientists should focus on management objectives and constraints when developing scientific techniques which can then be implemented by practitioners on an ongoing basis. Managers should develop more in depth and wider ranging knowledge about their sites and be prepared to evaluate and adapt management practices and systems if necessary.

It is important to sustain diversity in ecosystems and in the socio-economic environment. Integrated research methodologies are required for integrated management and sustainable development. Complete integration may not be possible but the aim is to develop more integrated approaches and to improve integration in all aspects of monitoring and management. To this aim we would welcome comments from readers, both scientists and managers, on their own experiences and recommendations.

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