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ABSTRACT

Dune vulnerability - a reduced ability to adapt to change, is of serious concern not only in Western Europe but on a world wide scale. To assess dune vulnerability, a main root checklist together with two daughter ones was devised. The main checklist comprised 6 categories (Site and dune morphology, beach condition, surface character of the seaward 200 m of dune, vegetation and protection measures) and dunes were classified according to their Vulnerability compared to Protection Measures. The Resilience daughter checklist encompassed dune erosion, sand input, sand retention, degradation by use and dune management. This was compared with risk factors such as obstacles to dune transgression and recreation. The GAVAM (Geomorphology, Aeolian, Vegetation, Anthropogenic, Marine influences) daughter checklist looked at 30 dune systems in the Gulf of Cadiz and assessed dune condition by a Vulnerability index (DVI) based on the above conditioning influences. Over 200 dune sites in Spain, France, Portugal and the UK were analysed by these means. Checklists confirmed that regional trends concerned with dune vulnerability could be assessed, although successful differentiation at the end of the dune spectrum (large sand sheets, e.g. Pyla, France and meadow formation, e.g. many of the UK systems) and at the local scale were muted. An innovative Aerial Digital Photographic System (ADPS) was developed and photographs successfully used to assess dune condition, anthropogenic impact on dune systems, etc. and was used to modify checklist procedures in assessing regional dune degradation. Principal Component analyses provided strong justification for the majority of checklist questions and the approach and relevance of the technique. The enumerated techniques provide valuable tools for dune managers. Rapid assessment of large areas of coastline can be obtained at a low cost and the resulting remote sensed images can provide a permanent record of the condition of the photographed dunes.

INTRODUCTION

With respect to this paper, the checklist is used as a 'problem delineation' procedure in which the major characteristics of the problem are listed, rated and evaluated with respect to dune vulnerability and protection. Papers by. For example, Williams *et al.*, (1993, 1994), Bodéré *et al.*, (1994), Alveirinho-Dias *et al.*, (1994), Davies *et al.*, (1995) have all followed this dictum. The structured procedure can be applied by managers from various discipline backgrounds and has advantages of economies of time and effort. The condition of a dune system may be summarised from topographic and geological maps, air photographs and predominantly field investigation. The checklist proforma, given in Appendix 1, is arranged in a manner to allow systematic consideration of the main parameters summarising the condition of a dune system. The three checklists are dealt with below but greater concentration has been focused on the daughter ones as many published papers (see references listed above) now inform with respect to the main root checklist.

THE CHECKLISTS

Main root checklist (Appendix 1),

The main categories of the root checklist are:

- A. Site and dune morphology.
- B. Beach condition.
- C. Surface character of the seaward 200m.
- D. Pressure of use.
- E. Vegetation
- F. Protection Measures

Methodology

Each parameter was rated separately and the rating scale recorded by ticking the appropriate box in the checklist (Appendix 1a). Percentages were calculated and summation of the first 5 sections gave a Vulnerability Index (VI). Similarly, the Protection Measure section can be scored to give a Protection Measure Index (PM). Pilot studies have shown that a VI/PM ratio between 0.8-1.3 represents a dune system in equilibrium; values higher or lower than these indicate out of equilibrium systems in a positive or negative phase. Dune vulnerability can either be analysed in this manner - see detailed analyses in Alveirinho-Dias *et al.*, (1994), Williams, *et al.*, (1993), Williams and Bennett, (1996), or via systems which have high/low vulnerabilities and high/low management responses, e.g. Davies *et al.*, (1995). An example of the approach is given below and in the section dealing with the Resilience checklist.

Results

The vegetation section was found to make small difference to the results apart from cases located at the extremes of the dune system spectrum of vulnerability, but it has been added for completeness as it is an important parameter in its own right with respect to dune systems. It should be noted that dune vulnerability refers to a system that can either be changing by excessive erosion processes at the dune front, or as a result of vegetation growth so that the system lacks bio-diversity e.g. dune pasture. Classic management approaches relate to analysis, planning, implementation and control, but most dune managers dislike reflective actions being more inclined to action. Any realised management strategy is a combination of strategies which can be deliberate (intended) and/or emergent (related to events which are not necessarily part of the intended strategy). The latter usually involves incremental responses to events and managers need to be adaptive, innovative, able to work together and learn from event. Crisis management is high risk and high cost management, and the best management challenge is to manage pre crisis events i.e. in the dune context via the checklist pre vulnerability conditions. Two examples show the two approaches.

Merthyr Mawr, Wales, UK (VI/PM 0.88, Fig. 1), is an SSSI dune system in equilibrium. This system is the most easterly surviving remnant of the once extensive South Wales dune system and covers 341 ha. The system has a rock base and the dune sands abut against a limestone scarp to a height of some 60m. They now form the western edge of the Glamorgan Heritage Coast. In 1840, sea buckthorn (*Hippophae rhamnoides*) was introduced to combat erosion and sand stabilisation was achieved in the 1920's. Buckthorn has become a major management problem as many dune areas are totally fixed and it is spreading at a rate of some 2 ha. per year. Proactive management is needed as dense sward precludes small species regeneration. Over the past 40 years, the almost complete lack of rabbits has led to

expansion of vegetation and dune stabilisation. Several foredune blowouts can be seen as a result of large scale sand and gravel extraction, which ceased in the early 1970's. It experiences a comparatively low visitor pressure (32%). Currently little management *per se* exists but designation as an NNR could result in establishing strategic plans.

Holywell, UK (VI=58%, PM= 66%), covers some 0.5 km², and has high management and vulnerability. Degradation to SW and NE access points has prompted management responses. Paths are well managed and boundary fencing has taken place but pedestrian access to most of the system is possible. The pressure of use is high as a result of access from a large military camp and the village. Whilst there is a measure of compatibility between the indices, an even higher response level is required to achieve sustainable levels of utilisation.

Daughter checklists - an alternative assessment of dune conditions

1) The GAVAM system (Appendix 1)

This coastal dune vulnerability index (DVI) summarises the condition of the system according to geomorphological and ecological resilience levels plus aeolian, marine and anthropogenic factors. Vulnerability is defined as the loss of capacity of a dune system to return to its original dynamic equilibrium after system displacement. The index classifies dunes in terms of response to various environmental changes that occur, both natural and human identifying the main source of vulnerability.

Methodology

Application of this Vulnerability Index proved to be useful in the assessment of the condition of coastal dunes, at least in England (Williams, 1998), France (Bodere *et al.*, 1991), Portugal (Alveirinho-Dias *et al.*, 1994; Matias *et al.*, 1998) and Spain (Garcia Mora *et al.*, 1997). A matrix with the values of the four characteristics of the checklist for 30 sample sites in Spain was submitted to a classification analysis using between group average clustering. The squared Euclidean distance was used as the measure for association. The total set of variables (Appendix 1) were placed into five main classes, initially identified as the main indicators of coastal dune vulnerability.

Vegetation composition was recorded between October 1996 and September 1998. At each site a 62.5 x 4 m transect was randomly laid along the sea facing slope of the frontal dune with the long axis parallel to the shore, avoiding the inclusion of secondary dunes or any other inland band. The transect was divided into 10, 6.25 x 4 m plots and species abundance for the transect was estimated as the average species cover in the 10 plots. Erosion/accretion processes were assessed at each site following the method of Flor (1990) on repeated surveys during 1996, 1997 and 1998. For example, recent sand input was easily assessed checking sand colour (fresh sand is lighter coloured than older sand deposits) or the development of new embryo dunes around litter or vegetation stems. Erosion was valued by noticing the presence of cliffs in the dune face, undermined roots or new blowout development. Stable foredunes were considered when no significant accretion nor erosion were noticed according to the above considerations.

Selection of the numbers and types of variables taken into consideration in the dune vulnerability classification procedure was performed according to the technique advocated by Cooper and McLaughlin (1998). As in the root checklist each selected variable was associated with a five point sliding scale graded from 0 to 4 with the latter being the most vulnerable. Similarly, the range of values for each variable ranking was based on the literature as well as on the consensus of multidisciplinary European coastal dune researchers. Partial

Vulnerability Indices were calculated by summation of variables ranking within each variable class, expressed as a percentage of the total available. A Dune Vulnerability Index (i.e. global vulnerability) was calculated as both the unweighted (DVI_1) and unweighted (DVI_2) average of the five partial vulnerability indices. Each Vulnerability Index ranged between 0 and 1, and as the index increases, the ability of the dune system to withstand further interventions decreases. Consideration of both global and partial vulnerabilities allows assessment of the dune system's condition as well as indicating the main source of imposed changes. For ease of interpretation, results can be presented graphically on a five axis figure, where each axis correspond to a vulnerability class. Linking all partial vulnerability, the resulting polygon area is a function of DVI (Fig. 2). Cluster analysis was used to group areas of similar characteristics according to the five partial vulnerability indices (Garcia Mora *et al*, in press) and each variable class was given a weight in the DVI_2 algorithm. The most important feature in dune formation, morphology and development was found to be sand particle size. Aeolian transport at any wind speed and therefore potential deflation effects were greater for fine than for coarse sands. Thirty contrasting coastal dune segments for developing a coastal dunes response classification were selected in the Iberian peninsula according to the vulnerability of the system to various natural and human factors (Garcia-Mora *et al*, in press)

Class variables (Appendix 1)

Marine Influence (MI) Wave parameters (height, length, energy, etc.), tidal range, coastal exposition, beach slope and particle size (Brown and Mclauchlan, 1990; Carter, 1995). Fetch is an indirect estimation of the coastal importance of these (Klijn, 1990). The dune system is limited in its seaward development by the storm tide height which may undercut or washover the dune. The narrower the backshore zone dissipating wave energy, the greater is the amount of marine erosion within that area and the potential seaward development of the coastal dune becomes less.

Aeolian Influence (AI) Wind exerts a large influence on foredune change depending on the sand budget. For example, under a uniform sand supply, backshore embryo dunes develop in pro-grading regressive coasts and supply sediment for accretion but in dune blowouts, sand can be blown inland decreasing dune resilience levels.

Vegetation Condition (VC) Differences in vegetation cover produce different morphological patterns in coastal dunes (Hesp, 1991), as well as the type of vegetation which determines its evolution. Plant morphological and physiological traits govern the efficacy of vegetation in both trapping and stabilising wind-blown sand. Coastal dune plants belong to three specific functionally based types.

- Type I consisting mainly of winter annuals, small size and soft leafed, with no presumed adaptations to the dune environment, prone to wave erosion.
- Plants of Type II are mostly perennials with a below-ground root network and leaves with adaptations to coastal environmental stress.
- Type III includes plants capable of being dispersed by sea-water and able to withstanding burial. Types 11 and 11 can stand disturbance.

Human Effects (HE) For example, agriculture, forestry, grazing of sheep and goats, mineral extraction, military training, urbanisation, industry, airports and both active and passive recreation. (Mayer, 1995). Anthropogenic effects on the coastal dunes can be divided into temporary (e.g. pedestrian and vehicle trampling, litter) and permanent (roads, housing, parking, crops, forestry).

Geomorphological Condition of the Dune System (GCD) The resilience capacity of a system will depend on the typology and extent of the coastal dunes (length, width, height, etc.). The bigger the system and sediment budget, the better become the ecological and geomorphological relations (van Der Meulen and Salman, 1993), and the more effective the buffering to extreme waves and wind (Carter, 1995).

Results

For the Gulf of Cadiz, Spain, the Dune Vulnerability Index algorithm was:

$$DVI_2 = (GCD + VC + 0.75MI + 0.75HE + 0.50AI) / 4$$

The two Dune Vulnerability indices, DVI_1 and DVI_2 , (see Methodology section), showed a very high correlation ($r = 0.98$). Since DVI_2 was based just on SW Iberian Peninsula coastal dunes results, DVI_1 was chosen to allow future comparison with other Spanish coastal areas. Cluster analysis revealed 4 main groups of coastal dune conditions (Garcia-Mora *et al*, in press). The results of the DVI_1 application enabled 4 dune groups to be recognised according to cluster groupings:

Group I dunes low vulnerability, DVI_1 below 0.25.

Group II dunes low to medium vulnerability, DVI_1 ranging between 0.25-0.5.

Group III dunes medium to high vulnerability, DVI_1 ranging between 0.5-0.6.

Group IV dunes high vulnerability ($DVI > 0.6$).

Discussion of Group III dunes ($n = 8$, $d.v. = 0.077 \pm 0.051$,; Fig. 2).

These are mainly vulnerable due to both the Geomorphological Condition of the System (GCD ranging from 0.62 to 0.84), and Marine Influence (MI, ranging from 0.41 to 0.69). Vegetation Condition, ranged from 0.48 to 0.65, and Aeolian Influences also contribute to the DVI. Beaches are very narrow and covered by water at high tide. Beach slopes are steep with no nearshore bars. Lack of sand sediment input places the systems under continuous marine erosion so washovers and bare cliffed foredunes prevail. Any vegetation present, usually Type II plants, display undermined roots and many paths cut through these dunes. It is the vulnerability of Plant Functional Type III species that makes the dunes sensitive to impact and foredune resilience loss can be understood in terms of a decrease in the plant diversity of these species. Management measures should focus on the maintenance of Type III plant populations in order to preserve the state of natural dune system. Discussion of the other types can be found in Garcia-Mora *et al*, in press).

Coastal dune vulnerability

In the SW Iberian peninsula only 13% of the sampled coastal dunes display low vulnerability values. These areas correspond to large entities of highly resilient dunes where management should focus on leaving these areas excluded from any human disruptive activities. Driving vehicles on the beach should be restricted to the inter-tidal zone, avoiding the destruction of beach mounds and vegetation. In the remainder 87% sampled dunes, the vulnerability of the system is increased by low GCD resilience levels (GCD values ranging from 0.61 to 1).

Besides low geomorphological dune resilience levels, in 31% of the sampled foredunes, marine effects increased the vulnerability of the systems by threatening these areas by erosion. Dunes are low on narrow beaches, mostly as a result of coastal exposure and restricted sand supply. The lack of sediment supply in the SW Iberian peninsula is caused by

damming and canalisation of the main rivers, dredging of river mouths, building on coastal dunes and building of groins at the river mouths. Coastal dunes persistence depends mainly on the restoration of the offshore sand balance.

This vulnerability index procedure enables an objective deduction to both potential vulnerability and the main source of imposed changes; indicating to dune managers where to focus the management strategy in each location. The proposed method provides a numerical estimation of coastal dune resilience levels to the main driving forces. This will allow assessment of progressive changes in the system as an aid in implementing preventive management strategies in advance of probable impacts. In addition, it also enables an objective coastal dune classification which would allow coastal dune monitoring both in the temporal as well as spatial context.

2) The RESILIENCE Checklist (Appendix 1),

In order to characterise biophysical vulnerability components of coastal dune systems, variables which could describe observable signs of degradation or regeneration of the system, as well as the type and necessity of managed response were obtained. Erosion forms originated by wind, waves or man and the evidence of sand blown inland from the system were selected as indicators of the dune system erosion condition: the presence (or absence) of recent or embryonic dunes was selected as an indicator of a positive (or negative) dune sediment budget; dune vegetation cover and damage state were selected as indicators of sand retention efficiency; signs left by several types of use were selected as indicators of anthropogenic dune degradation, and several measures that could be implemented to manage coastal dune systems, were listed. All variables selected are related to dune system elements and have a direct interest to management. Taking sensitivity (degree of transformation) and resilience capacity of a dune system as determinants to biophysical vulnerability, each variable was rated and evaluated in respect to three vulnerability levels - see later:

Portugal is an Atlantic facing country which to all intents and purposes is 'Mediterranean'. Portuguese case studies, raised the need of introducing a "non-applicable variable" alternative into the evaluation scheme. Non-applicable variables should not be considered in any VI index calculation. In the particular case of southern European coastal dunes, this would concern variables related to climate conditions and vegetation, for example "relative total area of wet slacks" (Section A, Appendix 1). To attribute to these variables a maximum score (4) due to their absence in these systems is to assume a high vulnerability that does not reflect a set of significantly distinct natural conditions from those of north west Europe. In fact, a long dry season, precipitation irregularity and less atmospheric and soil humidity in southern Europe generally determines a lower water level in dune aquifers and consequently a sparse dune vegetation cover. Over 50 Portuguese dune systems were investigated covering many different dune types : foredunes e.g. Mira, Tocha; climbing dunes e.g. S.Martinho do Porto, P. da Lagoa de Óbidos; perched dunes e.g. Burrinho-Samouqueira, Barrela; cliffed residual dunes e.g. Tombolo of Peniche, Caparica-Lagoa de Albufeira; artificial dunes e.g. Praia da Vieira; dune fields related to closed estuaries and lagoons e.g. Areia Branca; composite dune fields e.g. Guincho, Pessegueiro.

Rationale and structure

The Resilience checklist structure is based in selection of relevant coastal dune biophysical vulnerability components, including dune erosion, sand input, sand retention by vegetation, degradation and dune management. Each of these vulnerability descriptors gives specific information about the degree of transformation (sensitivity) and self-regulation capacity (resilience) of the coastal dune system (Tables 1-3). Variables describing

observable signs of dune degradation and regeneration, as well as the type and necessity of managed response, were obtained. All variables were related to dune system elements susceptible of receiving management intervention and having a direct interest to managers. Combining sensitivity and resilience of coastal dune systems, three major degrees of biophysical vulnerability can be recognised:

- low sensitivity and resilience threshold not exceeded;
- variable sensitivity and at the resilience threshold;
- high sensitivity and resilience threshold exceeded.

Each vulnerability descriptor takes into account the degradation level of the system and the corresponding desirable level of conservation (e.g. need to restrict utilisation and to implement general or specific management measures). Variables were rated and evaluated in respect to these three vulnerability degrees. Assessment of a dune system's attraction for recreation and tourism as well as of obstacles to dune transgression was also taken into consideration, with respect to their particular influence on a coastal dune's vulnerability. As this may lead to situations of biophysical, ecological and socio-economic damage, these parameters were considered as risk factors associated with dune vulnerability

Selected checklist variables and application principles

- Erosion forms originated by wind, waves or man and the evidence of sand blown inland from the system indicate the dune system's condition.
- The presence/absence of recent or embryo dunes indicate a positive/negative sand input.
- Dune vegetation cover and damage state indicate sand retention efficiency.
- Visible dune damage left by several types of use indicate man-induced degradation.
- Several measures that can be implemented to manage coastal dune systems were listed as indicators of dune management and conservation efficiency.
- Several land use categories were listed as indicators of dune transgression obstacles,
- Type and level of tourist accommodation on or near the coastal dune site, accessibility and parking, existing leisure areas and development level of seaside recreation are indicators of a dune system's attraction for recreation and tourism.

Data gathering took place at the end of a self-regeneration period, i.e. at the end of a geomorphologic cycle (late Spring / Summer), when sand input and sand retention by vegetation reach high values. Alternatively, assessment of human pressure and dune management efficiency at their peaks (by evaluating visitor damage control and induced-regeneration results) could take place in mid and late Summer. An exception can be made for land use data gathering, which should be obtained based on recent false colour aerial photographs covering a sufficiently broad inland area in respect to a coastal retreat for a time horizon of 50 years. Each selected dune site should correspond, if possible, to:

- an homogeneous site of the dune system, in respect to dynamic conditions, human pressure and geomorphologic features;
- a management unit.

Methodology

The total score found for each section of variables was calculated as a percentage of the maximum possible total value (score values from 0 to 2) and plotted (Figs. 4,6) The medium vulnerability degree was calculated as the average of the Σ of each vulnerability component (sections 1 to 5, Appendix 1) percentage. The final graph illustrates the relative

importance of each vulnerability component with respect to the dune's medium degree of vulnerability and shows the balance between dune vulnerability and risk factors. When the relative importance of one or the two risk factors exceeds the medium degree of vulnerability, the coastal dune system is in a potential or actual risk situation. introducing a "non-applicable variable" alternative into the evaluation scheme was taken into consideration. Non-applicable variables should not be considered to the maximum possible total score value for each section of variables, when calculating the respective percentage values (Laranjeira, 1998).

Results

The Mira foredune system was taken as a case study for the methodology and it is part of a beach-foredune coastline, about 50 km long, extending from Barra de Aveiro to Quiaios, Portugal (Andrade, 1985; Diaz, 1988). The selection of these sites to apply both checklist methods was based on previous fieldwork and aerial photography (false colour, 1:20 000, flight CELPA/CNIG/IF, 28/08/1995). Each selected site corresponded to a management unit, defined from the main access to the beach and distance of probable dispersion of visitors from that central point. Selected sites were monitored from winter 1996 to summer 1998. The two checklist method result comparisons presented below are examples are based on data gathered in July 1996 and February 1997.

Praia do Areão site

This has a cliffed foredune, with numerous natural breaches, both large (2-6m) and incised (>1m) at the dune cliff top. It is a rural beach, with low visitor numbers and little tourist attraction. Associated bare sand downdrift accumulations relate to an unmanaged footpath network, despite the low visitor pressure. Both beach and foredune sediment budgets are negative.

Main Checklist results (Fig. 3):

- pressure of use (Section D) is highly under-estimated, since dune degradation is mainly related to one factor (trampling) .
- VI/PM ratio of 5.6 (26/07/96) and of 5.4 (22/02/97) clearly showed that this is a highly under-managed site.

Resilience Checklist results (Fig. 4):

- This showed not only the importance of the dune management inefficiency (46.2%) to the Praia do Areão (medium degree of vulnerability), but also that such a degree of vulnerability was mainly due to a highly negative sediment budget and poor sand retention by foredune vegetation. However, use degradation is highly under-estimated as in the main root checklist (Fig. 3).
- this method also outlined that a properly managed and sign posted path network is needed if an increased number of visitors are to be expected.
- although relatively vulnerable, the system at Areão is not at risk, since there are not any obstacles to dune transgression and tourist attraction is still low (Fig. 3).

Praia de Poço da Cruz site

This is another rural beach, with low visitor numbers and tourist attraction. Traditional fishery is carried out in the area. The dunes have numerous breaches, incipient blowouts and associated bare sand downdrift accumulations related to an unmanaged path

deeply incised (>2m) path network. Both beach and foredune sediment budgets are negative. Sand traps have been installed in the main blowouts adjacent to main beach access paths.

Main root Checklist results (Fig. 5):

- Showed a slight difference between winter and summer human pressure and a poor balance between vulnerability and protection measures.
- Pressure of use (Section D) was highly under-estimated, since dune degradation was mainly related to one factor (trampling).
- Highly under-managed site, as showed by VI/PM ratio of 2.0 (26/07/96) and 2.3 (22/02/97).

Resilience Checklist results (Fig. 6):

- Showed a negative sand supply (83.3%) together with a very low management response (57.7%) as determinants to the medium degree of vulnerability. However, use degradation is highly under-estimated as in the root checklist.
- the method also outlined that properly managed and sign posted paths, extensive fencing, vegetation planting and access restriction are needed if increasing numbers of visitors are to be promoted.
- although relatively vulnerable, the system at Poço da Cruz is not at risk, since there are no obstacles to dune transgression and tourist attraction is still low.

REMOTE SENSING

Although visual analysis provides useful general information about the dune site and surrounding area, aerial photography gives an unparalleled opportunity to assess the condition of the dune quantitatively once they are rectified. Measurement of area and distance is possible, *e.g.* area of the dune field, area of bare sand and vegetation units *etc.* Path network densities in the dune field, and their relation to public access features such as the road network, car parks and holiday facilities, including hotels and camp sites can be measured.

The Aerial Digital Photographic System (ADPS) used for this project comprised three main components:

- Kodak Digital Science 460 CIR (colour infrared) camera supplied with two filters: CIR filter (650BP300) in the 500-800 nm spectral band, allowing wavelengths between 500 nm and 810 nm only to reach the CCD, so the cameras record in false colour infrared.
- VIS filter (VIS 550BP300) in the 400-700 nm spectral band enabling the CIR cameras to record natural colour.
- Aircraft mounting plate with a shock and vibration resistant chassis
- Power unit with intervalometer to manage the framing sequence

The assembly is self contained, transportable, easily mounted in a light aircraft within minutes and is easy to use (Edwards *et al.*, 1996). Colour infrared photography allows better discrimination between types of vegetation and assessment of plant vigour than true colour photography. The spectral sensitivity of the sensor in the CIR versions of the cameras was designed to mimic that of Kodak 2443 colour IR film (King, 1997). The range is governed by the quality and sensitivity of the silicon based CCD detectors and spans the entire spectrum of visible light, extending well into the near infrared (400 nm to 1000 nm).

Images are acquired and enhanced using Adobe Photoshop and then rectified in ER Mapper using ground control points derived from GPS survey and 1:25 000 IGN maps.

A direct transfer of checklist parameters to aerial digital photographic assessment was carried out at many locations. In this paper, results are presented from some thirteen sites investigated in September, 1998, over a 9km stretch of coastline along the Ile de Noirmoutier, France. (Fig. 7). Clearly, some questions of the checklist (8) could not be assessed by these means but overall, use of images increased the utility of the checklist by some 20%, which represents a significant improvement in the performance of this management tool. This is probably due to the more accurate interpretation of the wider dune context immediately visible on the images. It is difficult for a ground based observer to integrate and analyse spatial data related to length and area. Results shown in Fig. 7 show the similarity of form obtained by the two methods and demonstrates a progressive change in vulnerability from high in the north to low vulnerability in the south. The south has low visitor pressure and many areas of sand accumulation characterised by low prograding ridges. Fig. 8 summarises both surveys and again the overall north/south transition is maintained.

The area of the dune field was accurately determined in the digital images, as was the extent of vegetation cover and bare sand in the defined dune field. Vegetation cover in undisturbed dune areas can be recorded and this establishes a vegetation cover baseline from which a simple weighting factor can be calculated to compensate for naturally occurring variations in the completeness of the cover. For all areas, the total bare area in each dune site (both naturally bare and anthropogenically devegetated) was assessed, and the weighting factor applied to calculate the bare sand area resulting solely from anthropogenic impact. Loss of such vegetation poses a big threat to dune survival so is an indicator of the prevailing condition. Fig. 9a shows this for several mainland European regions. Additionally, path networks were digitised to define path length and path network density establishing their relationship with the area of the dune field and the area of bare sand. Vegetation loss in Mediterranean dune sites shows that this is the most degraded of the studied sites (Fig. 9a). This is because they are under the most pressure for tourism facilities. Many small dune fragments are surrounded by camp sites, hotel complexes with concomitant effects of human impact in evidence. Most NW France sites are small but show considerable variation in the degree of de-vegetation.

Site photos and/or CD's of raw images could easily be made available to dune managers or coastal agencies charged with sustainable use of such resources enabling widespread usage of these techniques. Increased pressure on European dune sites has resulted in increased degradation and insufficient knowledge of the pattern and extent of regional or national decline in this coastal resource. The extent of the natural vegetation cover in a dune system varies considerably and a wide range of physical controls e.g. sand supply operates. Notably in SW France, rapid sand accumulation occurs at the dune seaward edge with many prograding ridges being formed which support pioneer vegetation cover. Destruction of the vegetation cover is the main anthropogenic result.

MANAGEMENT

Presented results should not however be interpreted as merely representing 'well managed, under-managed and over-managed systems'. The figures shown are merely a visual representation of the actual field / management conditions at that site. Managers should refer to the details of the checklist when determining future management strategies (see Williams *et al.*, 1993, 1994; Williams, 1998; Davies, 1995).

The checklist enables spatial comparisons to be achieved, and repeated application of the procedure at specific sites would generate useful information on temporal changes. The latter in particular enables discontinuities to be detected. This is an important management requirement since environments do not necessarily change on a regular or orderly basis. Non linear variations are possible and monitoring through repeated application of the checklist should identify these changes. Whereas major gestalt shifts in the environment will be immediately apparent - for example foredune destruction in a major storm, and rapid strategic responses initiated, identification of subtle changes which could undermine the long - term survival of the system is a more significant management challenge.

An example of the above is given in Fig. 9b which shows the relationship between path length and de-vegetation. NW France suffers less than other regions and this is partly a function of climate, essentially rainfall and temperature. Paths are longer and narrower in NW France as a result of management strategy especially with respect to controlled car parks and channelling of visitors along controlled pathways. Wide pathways in the Mediterranean reflect an ease of access to the dunes for vehicles and paths leading to the beach tend to be aligned directly across low dunes. This leads to linked pathways and many more nodal points can be seen in this region, with a resulting loss of vegetation. Image techniques allows one to quantify this parameter and the use of change detection techniques in digital image time series can quickly identify further degradation or colonisation and recovery.

Principal Component (PC) analysis is a multivariate technique applied to data comprising in this case, sites in which many characters (questions) have been given numerical scores (on a scale between 0 and 4). The technique seeks to extract from the data components of variation representing orthogonal sub sets of the variation inherent in the data, the first few (principal) components representing the major trends/contrasts in the data. Co-variances were used in this paper as all characters were scored on a common numerical scale. The first three PC's accounted for 19, 12 and 8% of the total variation in the data (eigen values 17.5, 10.9 and 7.7 respectively) which tends to indicate that the data was homogeneous with a corresponding gradual transition between sites with contrasting characters. Fig. 10 indicates that six groupings occur. The group clustered close to the origin in Fig. 10 (covering some 13 questions) could probably be disregarded in the absence of strong theoretical arguments for their retention, but we would argue that the information is of a marginal interest to the manager and should be kept as it is of value and the time spent in gathering it is minimal. Component 1 represents the physical factors of dune building, contrasting the highest protection with the greatest threat to dune stability; Component 2 indicates human pressure factors, contrasting the highest human impact with the greatest protection.

CONCLUSIONS

A main checklist and two daughter ones were formulated and tested in dune systems in France, Portugal, Spain and the United Kingdom. The following points reflect the findings:

- The forcing functions on the coastal zone are a rising residential and tourist population pressure, in addition to military, commercial and industrial development.
- Dune resources in the medium term are finite and sustainable management of these resources as advocated in this paper is of strategic importance for social and economic development.
- Society should recognise that management strategies and techniques to maintain the integrity of the dune system, are of modest cost in comparison to the inherent value of the dune which is a sub set of the coastal system.
- A balance must be established between broad-scale management (national, regional) with targeted local management.

- Extensive, cost effective monitoring of dune systems (as an exemplar for coastal zone monitoring) is both possible, desirable and easily disseminated.
- The need for a co-ordinated European Coastal Zone management structure has never been greater. Extensive image data bases will undoubtedly inform decision making, promote sustainable management and maximise the safe envelope of economic development.

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C Dune breaches

D Blown sand

E Physical/Vegetation features

F Legislation

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Coastal dune vulnerability descriptor	Information
Dune erosion	if erosion is determinant to dune dynamics and degradation
Sand input (new dunes)	if accumulation is determinant to dune dynamics and sand supply abundant or insufficient to dune self-regeneration
Sand retention by vegetation	sand trap efficiency
Degradation by use	degree of man-induced degradation
Dune management	level, efficiency and need of management measures to mitigate degradation and stimulate regeneration

Table 1. Coastal dune vulnerability descriptors and associated information on sensitivity and resilience

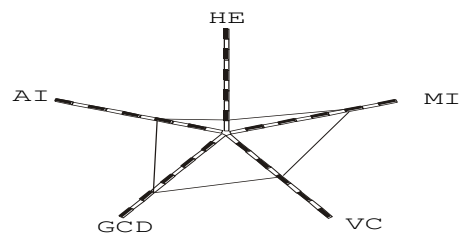
Coastal dune vulnerability degree	Description
Degree 1- <i>low sensitivity and resilience threshold not exceeded</i>	undergone change does not risk self-regeneration; increased use only with general measure implementation
Degree 2- <i>variable sensitivity and at the resilience threshold</i>	undergone change does not risk yet self-regeneration, though some degradation is already visible; some/partial use restriction may be needed as well as specific measure implementation
Degree 3- <i>high sensitivity and resilience threshold exceeded</i>	severe change and no sign of self-regeneration ; total use restriction may be needed as well as specific measure implementation

Table 2. Resilience checklist vulnerability degrees.

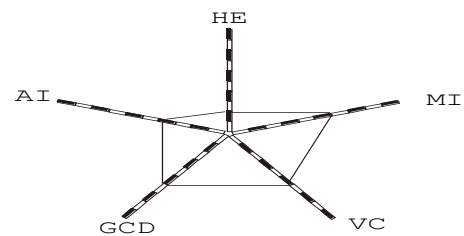
Factors that increase coastal dune vulnerability (risk factors)	Information
Obstacles to dune transgression	degree to which dune movement is limited by existing land use, preventing the system to adapt
Recreation and tourism attraction	degree to which dune degradation may increase in response to visitors pressure

Table 3. Resilience checklist risk factors

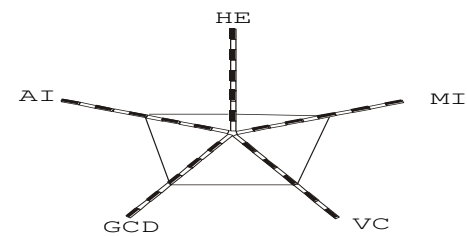
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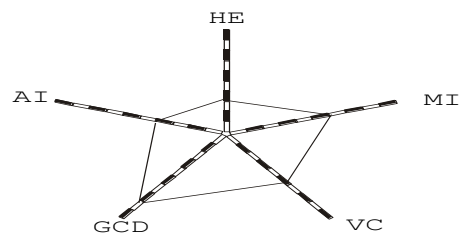
Dunas Douradas



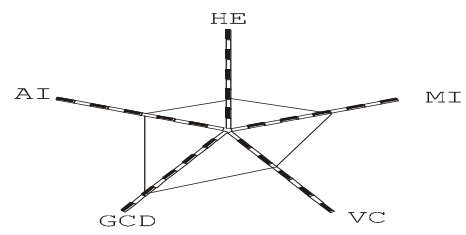
Tavira



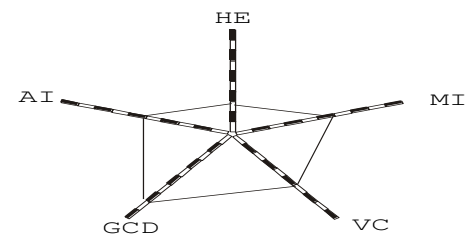
Redondela



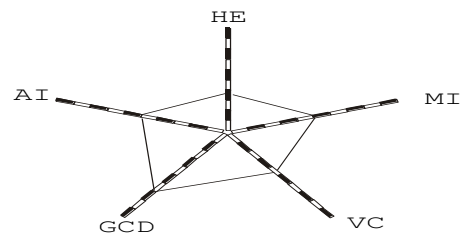
Bota W.



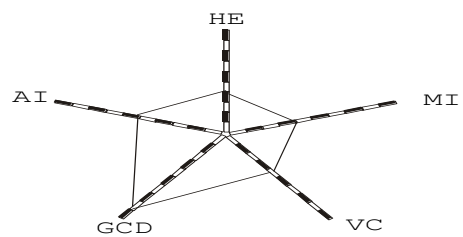
San Fernando



Enebrales



Cortadura



Taray

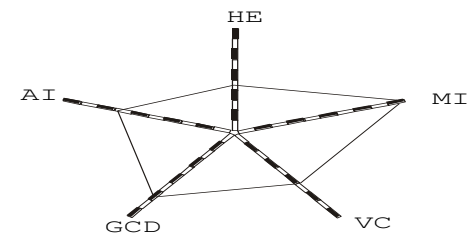


Figure 3 - Graphic representation of Root Checklist -Areão

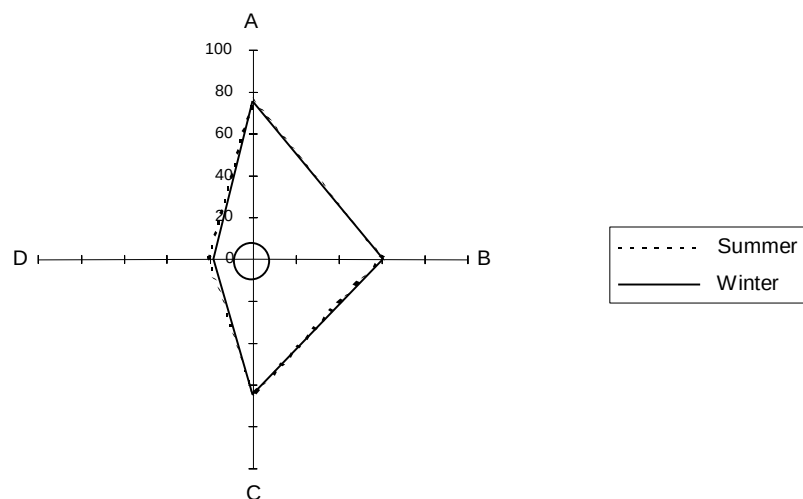


Figure 4- Graphic representation of Resilience Checklist - A reão

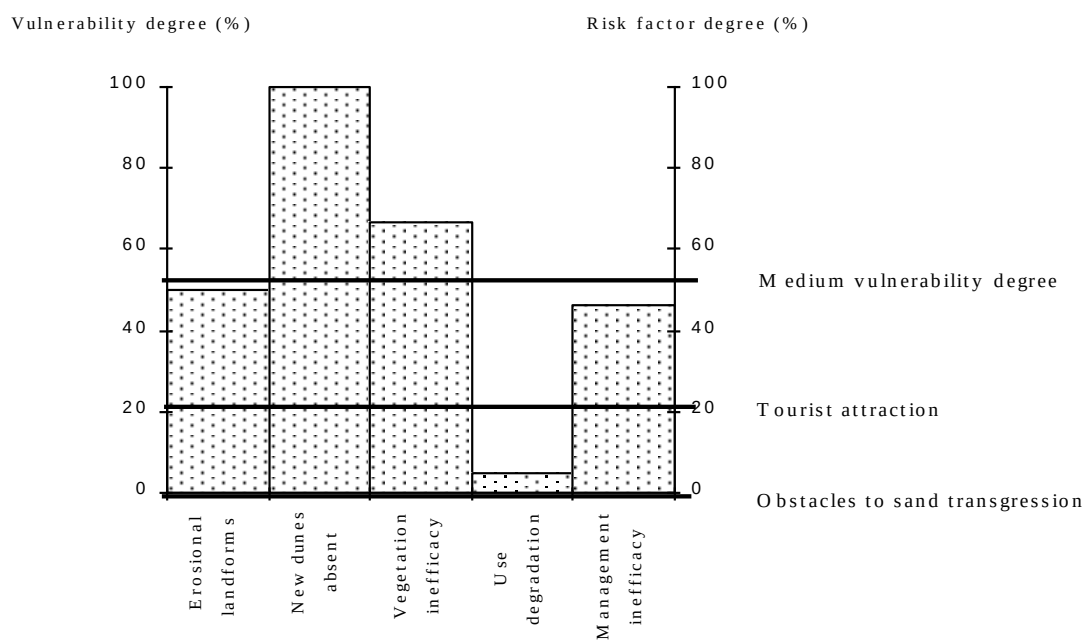


Figure 5-Graphic representation of Root Checklist - Poço da Cruz

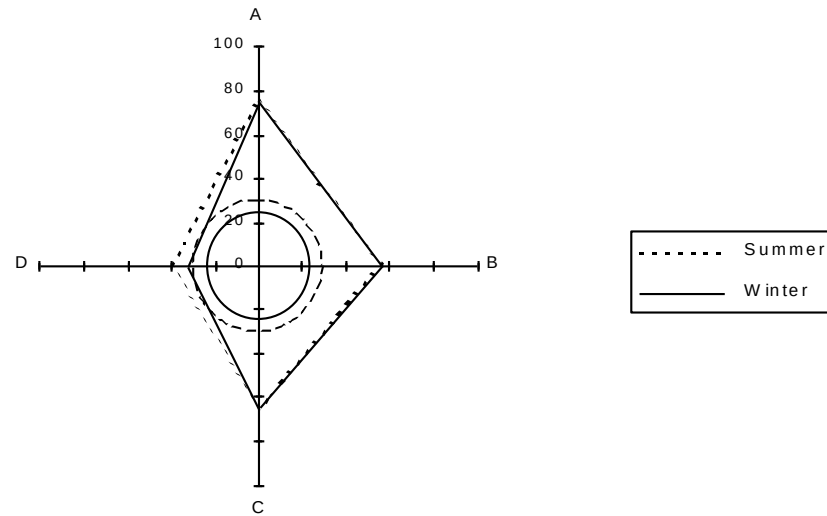
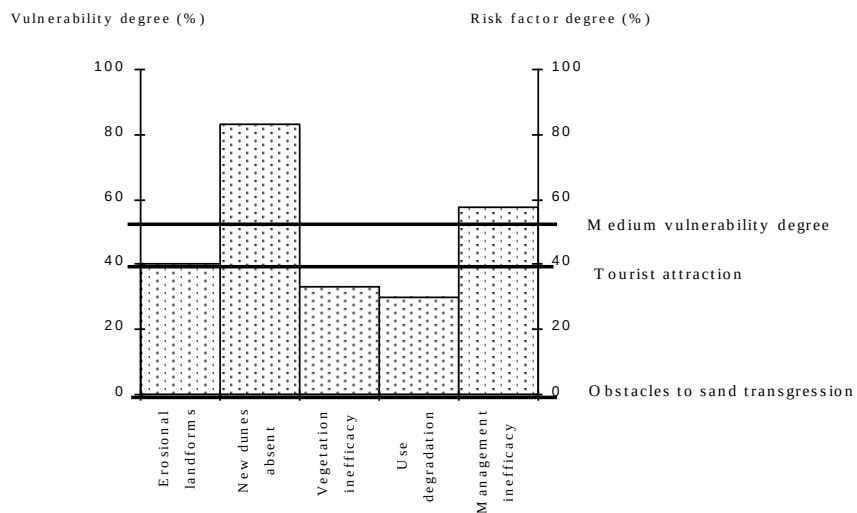


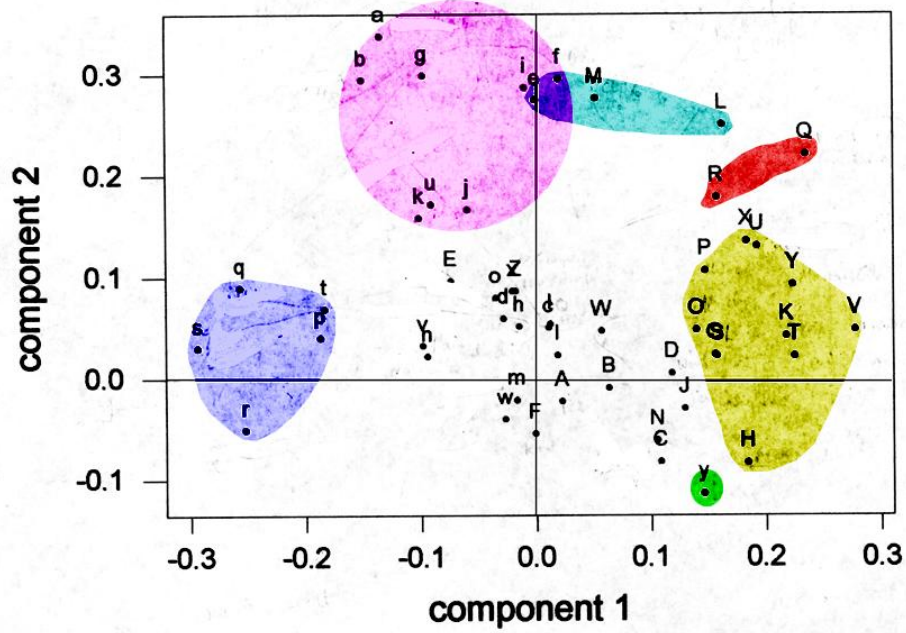
Figure 6 - Graphic representation of Resilience Checklist - Poço da Cruz



Total data (136 sites, 51 chars)

E-vector plot (136 cases = sites)

E:\pca\totpfrok.mpj



Chars 1-51 = A-Z,a-y

Fig 10

Appendix 1A. Coastal Sand Dune Vulnerability Checklist. - Main root checklist

		SCORES				
Section A - Site and dune morphology		0	1	2	3	4
1	Slope of inter-tidal zone	gentle slope []		medium []		steep slope []
2	Length of dune coast (km)	> 20 []	> 10 []	> 5 []	> 1 []	> 0.1 []
3	Width of dune belt (km)	> 5 []	> 2 []	> 1 []	> 0.1 []	< 0.1 []
4	Maximum height of dunes (m) from MHWS	> 25 []	> 10 []	> 5 []	> 1 []	< 1 []
5a	If ridged - number of major ridges (< 1 m)	> 10 []	5-9 []	3-4 []	2 []	1 []
5b	If plastered to slope - slope steepness	moderate []		gentle []		steep []
5c	If perched on cliff - cliff height (m)	< 2 []		2-5 []		> 5 []
6	Relative total area of low zones/wet slacks	moderate []		small []		none []
7	Particle size in foredunes/upper beach	100-200		200-400		>400 / <100
	Compare particle size with index Phi sizes	=< -1 []	0 []	+ 1 []	+ 2 []	+ 3 []
8	Infra-tidal topography	elevated structures		flat		canyons
Total score/percentage						
Section B - Condition of the beach						
1	Width of inter-tidal zone (km)	> 0.5 []	> 0.2 []	> 0.1 []	> 0.05 []	< 0.05 []
2	Sand supply input	high []		moderate []		low []
3	Pebble cover as % of surface	0 []	< 5 []	> 5 []	> 25 []	> 50 []
4	% foredunes cliffed by the sea	0 []	< 25 []	> 25 []	> 50 []	> 75 []
5	Dune cliff as % dune height	0 []	< 25 []	> 25 []	> 50 []	> 75 []
6	Breaches in seaward face	none []		some []		many []
7	Width of breaches in seaward face	< 2 []		2-10 []		> 10 []
8	Seaweed on upper beach	much []		some []		none []
9	Colonisation by vegetation in zone between dune face and HWSM	much []		some []		neg []
Total score/percentage						
Section C - Surface character of seaward 200m						
1	% system surface unvegetated	< 10 []	> 10 []	> 20 []	> 40 []	> 75 []
2	Blowouts as % of system area	< 5 []	> 5 []	> 10 []	> 20 []	> 40 []
3	Sand blown inland from system	little []		some []		much []
4	Saltwater invasion of dunes	none []		some []		much []
5	% new dunes along seaward edge	> 50 []	> 25 []	> 5 []	< 5 []	0 []
6	% breaches with new dunes	> 75 []	> 50 []	> 25 []	> 5 []	0 []
7	% seaward dune front vegetated	> 90 []	> 60 []	> 30 []	> 10 []	< 10 []
8	If recent sand deposition assess colonisation by marram, <i>Elymus</i> etc	much []		some []		none []
9	% impenetrable cover	some []		little []		none/much []
10	Frontal change since 1940	advance []		oscil. []		retreat []
11	Vegetation cover change since 1940	inc. []		oscil. []		decr. []
12	Relic quarries in frontal 200m	none []		small []		large []
Total score/percentage						
Section D - Pressure of Use						
1	Visitor pressure	low []		moderate []		high []
2	Road access	none []		moderate []		good []
3	On-dune driving	none []		some []		much []
4	Horse riding	none []		some []		much []
5	Path network density	low []		medium []		high []
6	Paths incised	little []		moderate []		deep []
7	Commercial camping	little []		some []		much []
8	Dispersed camping	little []		some []		much []
9	Housing	little []		some []		much []
10	Owners	one []		some []		many []
11	Main owner/manager	protection org's []		public		private []
12	Commercial/random extraction	none []		some []		much []
13	Grazing by cattle/sheep/goats	none []		some []		much []
14	Rabbit population	small []		moderate []		large []
Total score/percentage						
Vulnerability score and index						

Section E - Vegetation

1. % Cover of foredune type species in the beach	> 50 []	> 25 []	> 15 []	> 5 []	< 5 []
2. % Cover of foredune type species in the sea-side of the frontal dune	> 90 []	> 60 []	> 30 []	> 15 []	< 15 []
3. Relative proportion of secondary type species in the sea-side of the frontal dune	< 5 []	< 15 []	< 30 []	< 60 []	> 60 []
4. Relative proportion of inland type species in the sea-side of the frontal dune	< 1 []	> 1 []	> 5 []	> 10 []	> 30 []
5. Relative proportion of exotic species in the sea-side of the frontal dune	0 []	< 1 []	< 5 []	< 15 []	> 15 []
6. Relative proportion of foredune and secondary type species in the 100m inland of the frontal dune	> 75 []	> 50 []	>25 []	> 10 []	< 10 []
7. Relative proportion of vigorous plants or plants with normal vitality in the sea-side of the frontal dune	> 75 []	> 50 []	> 25 []	> 10 []	< 10 []
8. Relative cover of exposed roots	< 5 []	> 5 []	> 15 []	> 25 []	> 50 []
9. Relative proportion of plants with obvious effects of physical damage	< 5 []	> 5 []	> 15 []	> 25 []	> 50 []
10. % vegetation removal in the sea-side of the frontal dune due to natural disturbance	< 10 []	> 10 []	> 25 []	> 50 []	> 75 []
11. % vegetation removal in the sea-side of the frontal dune due to human disturbance	< 10 []	> 10 []	> 25 []	> 50 []	> 7 []

Total score/percentage

Section F - Recent protection measures

1. Surveillance and maintenance	none []		some []		much []
2. % area with restricted access	0 []	< 10 []	> 10 []	> 25 []	> 50 []
3. Controlled parking	none []		some []		all []
4. Horse riding controlled	none []		some []		all []
5. On-dune driving controlled	none []		some []		all []
6. Managed paths	none []		some []		all []
7. Sand traps	few []		some []		many []
8. Planting on mobile areas (%)	0 []	< 10 []	> 10 []	> 25 []	> 50 []
9. Information boards	none []		some []		many []
10. If protection against marine erosion, impact on the dune	neg. []		some []		much []
11. Protection by legislation	weak []		moderate []		str. []

Appendix 1B, coastal dune vulnerability critical thresholds - Resilience checklist

Section 1- Dune erosion.

vulnerability degree		1	2	3
Variable		score 0	score 1	score 2
Marine erosion	Cliffed foredune	-absent	-as <50% of foredune length	-as >50% of foredune length
	Dune cliff as % of dune height	-<25%	-25%- 50%	->50%
	Recent overwash	-absent		-present
Wind erosion (natural and man-induced)	Active breaches	-absent -poorly incised breaches (<1m) in <50% of system length	-poorly incised breaches (<1m) in <50% of system length - very incised breaches (>1m) in <50% of system length	-very incised (>1m) and/or large (>2m) breaches in >50% of system length
	Active blowouts	-absent	-incipient blowouts as <1/3 of system area -main blowout as <1/3 of system area	- incipient blowouts as >1/3 of system area -large blowout(s) as >1/3 of system area

	Sand blown inland from system	-absent	-small sand accumulations are observable; damages not yet reported	- intervention is needed to mitigate observable/ reported damages - damages already led to intervention
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Section 2- Sand input (new dunes).

vulnerability degree Variable	1 score 0	2 score 1	3 score 2
Recent or embryo dunes along seaward edge	-along >50% of system length	-along <50% of system length	-absent
% breaches with new dunes	->50%	-<50%	-none
% blowouts with new dunes	->50%	-<50%	-none
Overwash with new dunes	-partial reconstruction of dune ridge	-isolated embryo dunes	-none

Section 3- Sand retention by vegetation.

vulnerability degree Variable	1 score 0	2 score 1	3 score 2
% system surface unvegetated	-<25%	-25%- 75%	->75%
% seaward face vegetated	->50% of seaward face length	-10%- 50% of seaward face length	-<10% of seaward face length
Damaged state of seaward face vegetation	- vegetation removal and plants with exposed roots as <25% of vegetated seaward face	- vegetation removal and plants with exposed roots as 25%- 75% of vegetated seaward face	-vegetation removal and plants with exposed roots as >75% of vegetated seaward face

Section 4- Degradation by use.

vulnerability degree variable	1 score 0	2 score 1	3 score 2
Access beach path network density	-paths through dune ridge at specific points; low density	-paths through dune ridge at specific points; high density -diffuse path network; low density	-diffuse path network; high density
Incised paths	-little (<1m)	-moderate (<2m)	-deep (>2m)
On-dune driving	-none	-some; localised tracks	-much; diffused tracks
Horse riding	-none	-some; localised tracks	-much; diffused tracks
Non-commercial camping	-none	-some; dispersed	-much; at preferential locations
Commercial camping	-none	-as <1/4 of system area	-as >1/4 of system area
On-dune urban areas or housing	-none	-isolated construction -disperse housing as <1/4 of system area	-disperse housing as >1/4 of system area -urban area
Sand extraction	-none -not causing significant degradation	-causing destruction of <1/4 of system area	-causing destruction of >1/4 of system area
Fishery activities	-none -not causing significant degradation	-causing destruction of <1/4 of system area	-causing destruction of >1/4 of system area

Sport camps (green and others)	-none	-partial occupation of system area	-total occupation of system area
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Section 5- Dune management.

vulnerability degree		1	2	3
variable		score 0	score 1	score 2
General measure	Managed paths	-all; elevated walkways	-all or only main access paths; walkways	-none
	Information boards	-one or several boards, well conceived and strategically placed	-one or several boards, in bad condition, wrong conception, mis-placed	-none
	On-dune driving controlled	-not necessary -efficient (protection by legislation applied)	-insufficient (some tracks visible; protection by legislation not efficiently applied)	-none
	Horse riding controlled	-not necessary -efficient	-insufficient (some tracks visible)	-none
	Non-commercial camping controlled	-not necessary -efficient (protection by legislation applied)	-insufficient (damages visible; protection by legislation not efficiently applied)	-none
	Housing/construction controlled	-efficient (protection by legislation applied)	-insufficient (protection by legislation not efficiently applied)	-none
	Sand extraction controlled	-efficient (protection by legislation applied)	-insufficient (damages visible; protection by legislation not efficiently applied)	-none
	Fishery activities controlled	-not necessary -efficient (protection by legislation applied)	-insufficient (damages visible; protection by legislation not efficiently applied)	-none
Specific measure	Sand traps	-none and/or not necessary -sand traps in all deflation areas (blowouts/ breaches) for dune regeneration	-absent/insufficient, but necessary in <25% of system area	- absent/insufficient, but necessary in >25% of system area
	Planting on mobile bare sand areas	-none and/or not necessary -strategic planting program for dune conservation	-absent/insufficient, but necessary in <25% of system area	- absent/insufficient, but necessary in >25% of system area
	Beach or dune nourishment	-not necessary	-present, with successful results	-necessary -present, without successful results
	Restricted access	-none and/or not necessary -strategic access restriction for dune conservation	-absent/insufficient, but necessary in <25% of system area	- absent/insufficient, but necessary in >25% of system area
Defence coastal engineering		-none	-jetties, downdrift from system	-seawalls -jetties, updrift from system

II - FACTORS THAT INCREASE COASTAL DUNE VULNERABILITY (RISK FACTORS)

Section A- Obstacles to dune transgression.

Degree of dune transgression limitation	Free transgression	Transgression partially limited, increasing dune vulnerability	Transgression totally limited, determining high dune vulnerability
Land use categories	score 0	score 1	score 2
Natural areas	->75% brushwood	->75% forest	->50% agricultural areas -absent
Urban areas	-absent	->50% dispersed urban areas	->50% concentrated urban areas

Other areas	-absent	->50% sport camps -camping -others	
Roads	-unpaved roads	-secondary roads	-main roads -railway lines

Section B- Recreation and tourist attraction.

Visitors pressure	Low visitors pressure	Moderate to high visitors pressure, increasing dune vulnerability	Very high visitors pressure, determining high dune vulnerability
Recreation and tourist attraction	score 0	score 1	score 2
Level of tourist accommodation	-none -low (rural setting) (1)	-moderate (rural and urban setting) (2)	-high (rural and urban tourist setting) (3)
Road access and parking	-no access roads -bad access to dune system and no parking	-reasonable access to dune system and parking	-good access to dune system and parking
Leisure areas	-absent	-present, but in bad condition	-present and in good condition
Development level of seaside recreational activities	-beach in natural setting; without development	-beach in rural setting; low development (4)	-beach in urban setting; high development (5)

Notes	Additional information
1	Low level of tourist accommodation (rural setting), including camping and low hostels capacity; a few summer homes
2	Moderate level of tourist accommodation (rural and urban setting), including camping, hostels and low capacity holiday villages; low number of summer homes
3	High level of tourist accommodation (rural and urban tourist setting), including all forms of high capacity tourist accommodation; high number of summer homes
4	Rural beach with low development, including lifeguard and refreshments/ restaurants
5	Urban beach with high development, including lifeguard, sunshades, sanitary and shower facilities, refreshments/ restaurants, open games and sports facilities and equipment storage

Appendix 1C. Dune Vulnerability Checklist. The GAVAM checklist.

1. Geomorphological Condition of the Dune System (GCD):

1.Length of homogeneous active dune system (Km)	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	>20	>10	>5	>1	>0.1
2.Width of dynamic dune system (Km)	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	>2	>1	>0.5	>0.1	<0.1
3.Width of front dune as % of active dune system	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	<5%	<25%	<50	<75	>75
4.Average height of secondary dunes (m)	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	>25	>10	>5	>1	<1
5. Average height of frontal dunes (m)	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	>25	>15	>10	>5	<5
5a.If ridged, number of major ridges	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	>10	>4	>2	2	1
5b.If plastered to slope, slope steepness	☐ 0		☐ 2		☐ 4
			moderate	gentle	steep
5c.If perched on cliff-cliff height (m)	☐ 0		☐ 2		☐ 4
	>2		2-5		>5
6.Relative area of wet slacks (%)	☐ 0		☐ 2		☐ 4
			moderate	small	none
7.Degree of dune system fragmentation (%)	☐ 0		☐ 2		☐ 4

	Low		medium		high
8. Particle size of the frontal dune- Phi sizes	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	>-1	0	1	2	3

Total Score/percent:

2. Marine Influence (MI):

1.Orthogonal fetch (Km)	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	<25	<100	<250	>500	>1000
2.Berm slope	☐ 0		☐ 2		☐ 4
	moderate		gentle		steep
3.Width of inter-tidal zone (Km)	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	>0.5	>.2	>.1	>.05	<.05
4.Tidal range (m)	☐ 0		☐ 2		☐ 4
	<2m		2-4 m		>4m
4.Coastal orientation	☐ 0		☐ 2		☐ 4
	10-45°		0-10°		0°
5.Width of the zone between HWSM and dune face (m)	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	>75	<75	<25	<10	0
6.Breaches in the frontal dune due to wash over, relative total area (%)	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	0%	<5%	<25%	<50%	>50%
7.% frontal dune cliff by the sea or with only ephemeral dunes as % of dune height	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	0	<25	>25	>50	>75
8. Particle size of the beach: Phi sizes	☐ 0		☐ 2		☐ 4
	>2		0-2		<0

Total score/percent:

3. Aeolian Influence (AI):

1. Sand supply input	☐ 0		☐ 2		☐ 4
	High		moderate		low
2. % cover of embryo dunes along the seaward edge.	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	>50	>25	>5	<5	none
3.blowouts: % of the system.	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	<5%	<10%	<25%	<50%	>50%
4 Aeolian breaches in seaward face not induced by trampling: % of the system	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	<5%	<10%	<25%	<50%	>50%
4.1.If breaches, depth as % of dune height	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	<5%	<10%	<25%	<50%	>50%
5. Natural litter drift cover as % surface cover	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	0%	<5%	>5%	>25%	>50%
6. Pebble cover as % surface	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	0%	<5%	>5%	>25%	>50%
7. Shell cover as % surface on upper beach.	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	0%	<5%	>5%	>25%	>50%
8. % seaward dune vegetated	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	>90	>60	>30	>10	<10
9. % of the System unvegetated	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	<10	>10	>20	>40	>75

Total score/percent:

4. Vegetation Condition (VC):.

1. %cover of Type III plants in the beach	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	>50	>25	>15	>5	<5
2. %cover Type III plants in the seaside of the frontal dune	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	>90	>60	>30	>15	<15
3. Relative proportion of Type II plants in the seaside of the frontal dune (%)	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	<5	<15	<30	<60	>60
4. Relative proportion of Type I plants in the seaside of the frontal dune (%)	☐ 0	☐ 1	☐ 2	☐ 3	☐ 4
	<1	>1	>5	>10	>30

5. Relative proportion of exotic species in the seaside of the frontal dune (%)	☐ 0 0	☐ 1 <1	☐ 2 <5	☐ 3 <15	☐ 4 >15
6. Relative proportion of Type II & III plants in the 100 m inland of the frontal dune (%)	☐ 0 >75	☐ 1 >50	☐ 2 >25	☐ 3 >10	☐ 4 <10
7. Relative proportion of vigorous plants or plants with normal vitality in the seaside of the frontal dune (%)	☐ 0 >75	☐ 1 >50	☐ 2 >25	☐ 3 >10	☐ 4 <10
8. Relative cover of exposed roots in the seaside of the frontal dune (%)	☐ 0 <5	☐ 1 >5	☐ 2 >15	☐ 3 >25	☐ 4 >50
9. Relative proportion of plants with obvious effects of physical damage (%)	☐ 0 <5	☐ 1 >5	☐ 2 >15	☐ 3 >25	☐ 4 >50
10. % Vegetation removal in the sea-side of the frontal dune due to human disturbance (%)	☐ 0 <10	☐ 1 >10	☐ 2 >25	☐ 3 >50	☐ 4 >75

Total score/percent:

5. Human Effect (HE):

1. Visitor pressure	☐ 0 Low		☐ 2 Moderate		☐ 4 High
2. Visitor frequency	☐ 0 Low		☐ 2 Moderate		☐ 4 High
3. Access difficulty	☐ 0 High		☐ 2 Moderate		☐ 4 Low
4. On dune driving	☐ 0 None		☐ 2 Some		☐ 4 Much
5. On beach driving	☐ 0 None		☐ 2 Some		☐ 4 Much
6. Horse riding	☐ 0 None		☐ 2 some		☐ 4 Much
7. Path network as percent of the frontal dune	☐ 0 0%	☐ 1 <5%	☐ 2 >5%	☐ 3 >25%	☐ 4 >50%
7.1. Path width (m)	☐ 0 <1	☐ 1 <2	☐ 2 <3	☐ 3 <5	☐ 4 >5
7.2. Paths incised as percent of the frontal dune height	☐ 0 <5	☐ 1 <25	☐ 2 <50	☐ 3 >50	☐ 4 >75
8. Anthropogenic litter: cover as % surface cover	☐ 0 0%	☐ 1 <5%	☐ 2 >5%	☐ 3 >25%	☐ 4 >50%
9. Sand extraction (building etc.)	☐ 0 0%	☐ 1 <5%	☐ 2 >5%	☐ 3 >25%	☐ 4 >50%
10. Beach cleaning regime (daily, weekly etc.)	☐ 0 low		☐ 2 Moderate		☐ 4 High
11. % upper beach cleaned	☐ 0 0	☐ 1 <25	☐ 2 <50	☐ 3 <75	☐ 4 >75
12. % permanent infrastructure replacing active dunes, (houses, roads etc.)	☐ 0 0	☐ 1 <25	☐ 2 <50	☐ 3 <75	☐ 4 >75
13. % ephemeral infrastructure replacing active dunes (outdoor facilities, camping, etc.)	☐ 0 0	☐ 1 <25	☐ 2 <50	☐ 3 <75	☐ 4 >75
14. Relative surface forested in the system (200m inland from the foredune) (%)	☐ 0 0	☐ 1 <25	☐ 2 <50	☐ 3 <75	☐ 4 >75
15. Relative cover of agriculture in the system (200m inland from the foredune) (%)	☐ 0 0	☐ 1 <25	☐ 2 <50	☐ 3 <75	☐ 4 >75
16. Grazing on the active system	☐ 0 none	☐ 1 low	☐ 2 moderate	☐ 3 high	☐ 4 Intensive
17. Rabbit numbers	☐ 0 none	☐ 1 low	☐ 2 moderate	☐ 3 high	☐ 4 Intensive

Total score/percent:

