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A RESILIENCE CHECKLIST TO EVALUATE COASTAL DUNE VULNERABILITY

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ABSTRACT

The aim of the proposed resilience checklist is to easily evaluate foredune vulnerability when applied to management. It focus on: (i) the definition of the level of pressure for each use in relation to the foredune resilience threshold, (ii) the direct identification of the system components more vulnerable and (iii) the recognition of management readjustments needed, in order to prevent or minimise impacts.

The resilience checklist structure is based on a selection of relevant coastal dune vulnerability descriptors, giving information about the system sensitivity and resilience. All variables selected describe observable signs of foredune degradation or regeneration and are related to system elements susceptible of receiving management intervention.

Three major degrees of biophysical vulnerability are recognised: a) Degree 0 - low sensitivity and resilience threshold not exceeded; b) Degree 1 - variable sensitivity and at the resilience threshold; c) Degree 2- high sensitivity and resilience threshold exceeded. Each degree takes into account the system's level of degradation and the corresponding desirable level of conservation.

The application example- Mira's beach southern sector- is a site under a very high summer pressure (seaside recreation and tourism). Three management phases were monitored, between 1996 and 1998. Checklist results show dune management inefficiency and an ineffective sand retention by vegetation as determinants to this foredune site vulnerability and that a planting program is still in need. However, a clear vulnerability decrease in this site was recognised.

1. INTRODUCTION

In the last 20 years coastal dune systems, namely foredunes, and morphodynamic models of the beach-dune interaction have been a major concern to the biophysical sciences. However, little attempt has been made to appropriately integrate the latest findings into management tools. In order to achieve this objective, Bodéré *et al* (1991) and William *et al* (1993) developed a checklist to assess and monitor coastal dune vulnerability, defined as accelerated erosion of the dune system mainly due to human pressure. To synthesise the condition of the coastal dune system, the main parameters included in the checklist are: A- Site and dune morphology; B- Beach condition; C- Surface character of the seaward 200m; D- Pressure of use and E- Protection Measures. Further methodology details may be found in Williams *et al* (1993), Davies *et al* (1995) and Williams and Bennett (1996).

The checklist applicability was tested, based on the characteristics of the NW European coastal dunes. Dias *et al* (1994) and William *et al* (1994) showed some difficulties in applying it to the SW European coast, namely in what concerns dune management evaluation. It should not simply consider the presence or absence of conservation measures in the system, but rather its effectiveness and efficacy.

Between 1996 and 1998, assessment of 35 coastal dune systems in the W Atlantic coast of Portugal was carried out by DILIF as a contribution to the project *European Land - Ocean Interaction StudiEs* "*Dynamics and Integrated Management Methods for Coastal Dune Ecosystems*" - ELOISE/DUNES (*Environment and Climate Program, European Commission DGXII MAST - Marine Science and Technology*), co-ordinated by A. Williams of Bath University. This research showed that dry season longer duration, precipitation irregularity and less atmospheric and soil humidity generally determines a lower water level in dune aquifers and a sparse dune vegetation cover, when compared to those of NW European coastal dune systems. Attribution of the maximum vulnerability score to the absence of “relative total area of wet slacks” (Section A), “colonisation by vegetation in zone between dune face and HWSM” (Section B) and “relative total area of impenetrable cover” (Section C) is to assume a high vulnerability that doesn't reflect the SW European coastal dunes reality. These evidences point out the need to review the checklist evaluation scheme regarding the variables related to climate conditions and vegetation, in order to adapt it to a broader range of dune systems.

With respect to dune management, the research stressed the relevance of evaluating each system conservation measures, based on sand supply and human pressure. This raises the need to incorporate a distinction in the checklist structure between necessity of general measures implementation (*e.g.* parking and on-dune path management, information boards, surveillance and maintenance) from that of specific measures (*e.g.* restricted access, sand traps, planting programs), which should be established by or with experts.

Attempting to improve European coastal dune vulnerability assessment and give a contribution to ELOISE/DUNES project a new checklist is proposed, based on the resilience threshold concept (Laranjeira, 1997; Laranjeira *et al,* in press). Its application to a selected number of foredunes in the Portuguese coast led us to the necessity of some improvements in order to become it easier to apply by environmental managers.

2. Methodological Approach

In the environmental management context, the carrying capacity expresses an intensity of use and establishes a physical dimension (*e.g.* number of visitors, buildings, boats) or level of development to a human activity which a particular biophysical system may permanently sustain, without an irreversible degradation.

The difficulty in applying the concept is that there is no single and absolute value to define a system carrying capacity at a particular moment. The "starting condition" of a system should not be immediately regarded and adopted as the reference situation, given the fact that it can only represent a particular state within the long term evolution tendency of the system, which should be known or recognised. Further more, the carrying capacity definition is largely dependent on management policy objectives and decisions. However, it is possible to recognise land use critical thresholds, whenever biophysical systems show signs of degradation, *i.e.* the biophysical systems are unable of self-regulation (resilience capacity).

The carrying capacity concept focus on biophysical systems as resources needed to implement or develop a human activity. The resilience capacity concept focus on consequences to biophysical systems dynamic evolution due to land use. Thus, from this perspective, whenever a biophysical system shows generalised and persistent evidences of degradation, the resilience threshold is exceeded.

As to foredune morphodynamic variability, the resilience assessment must be done after a period no less than two years, better after ten years.

The aim of the proposed resilience checklist is to easily evaluate foredune vulnerability when applied to management. Given its major purpose, the resilience checklist rationale focus on: (i) the definition of the level of pressure for each use in relation to the resilience threshold, (ii) the direct identification of the system components more vulnerable and (iii) of management readjustments needed, in order to prevent or minimise pressure impacts.

The resilience checklist structure is based on a selection of relevant coastal dune biophysical vulnerability descriptors, giving information about the system sensitivity (transformation degree) and resilience: (i) dune erosion; (ii) sand input; (iii) sand retention by vegetation; (iv) dune degradation by use; (v) dune management (Table 1).

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

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
Dune degradation by use	degree of man-induced degradation
Dune management	level, efficiency and need of management measures to mitigate degradation and stimulate regeneration

For each vulnerability descriptor, a set of variables was selected in order to describe observable signs of foredune degradation or regeneration (see Appendix). All variables are related to system elements susceptible of receiving management intervention, having therefore a direct interest to managers. The aim of the variables selection was to characterise the dynamics and complexity of the foredune system in a clear and understandable way to managers, usually non-experts, allowing them to easily apply and interpret the checklist.

Combining sensitivity and resilience of foredune systems, three major degrees of biophysical vulnerability can be recognised: (i) Degree 0- low sensitivity and resilience threshold not exceeded; (ii) Degree 1- variable sensitivity and at the resilience threshold; (iii) Degree 2- high sensitivity and resilience threshold exceeded. Each degree takes into account the system's level of degradation and the corresponding desirable level of conservation, *i.e.* the need to restrict use and to implement general or specific management measures (Table 2).

Table 2 - Resilience checklist vulnerability degrees

Coastal dune vulnerability degree	Description
Degree 0 - *low sensitivity and resilience threshold not exceeded*	Undergone change does not risk self-regeneration; increased use only with general measure implementation
Degree 1 - *variable sensitivity and at the resilience threshold*	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 2 - *high sensitivity and resilience threshold exceeded*	Severe change and no signs of self-regeneration; total use restriction may be needed as well as specific measure implementation

Variables are characterised, rated and evaluated in respect to the three vulnerability degrees (see Appendix). As an example, three possibilities are given to characterise “cliffed dune as % of foredune length” variable, included in “Dune erosion” descriptor. These are, as follows: a) absent (score 0); b) present, as <50% (score 1); c) present, as >50% (score 2). Each alternative is rated, based in a numerical value (score) equal to its corresponding vulnerability degree. In order to calculate the vulnerability total for each descriptor, one must sum all values found for its variables. The total value obtained must then be converted as a percentage. Consequently, the minimum vulnerability of “Dune erosion” descriptor is 0 (zero) and the maximum is 12 (2x6 variables) or 100%.

With the dependent variables case, such as “dune cliff as % of foredune height”, these variables should not be considered to the sum of variable values for the correspondent descriptor. Therefore, in the particular case of cliffed foredune absent, the maximum vulnerability descriptor value would be 10 (2x5 variables) equal to 100%. The same logic applies to three variables of “Sand input” descriptor, namely breaches, blowouts and overwashes with new dunes, whenever one of these erosion forms is not present in the system.

Assessment of foredune system attraction for recreation and tourism, as well as of land use obstacles to natural aeolian transgressive dynamics, must also be taken into consideration, regarding their particular influence to coastal dunes vulnerability. As they may lead to situations of biophysical, ecological and socio-economic damage, these external elements to the foredune system are considered and evaluated as risk factors (Table 3). The risk factors calculation method is similar to the one of vulnerability variables and descriptors.

Data gathering should take place at the end of a self-regeneration period, that is at the end of a geomorphologic cycle (late Spring or late Summer), when sand input and sand retention by vegetation reach high values. On the other hand, assessment of human pressure and foredune management efficiency at their peaks should take place in mid and late summer, by evaluating visitor damages control and induced-regeneration results.

Table 3 - Resilience checklist risk factors

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

Exception is 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 foredune site should correspond, as possible, to: (i) an homogeneous site of the system, in respect to dynamic conditions, geomorphologic features and human pressure; (ii) a management unit.

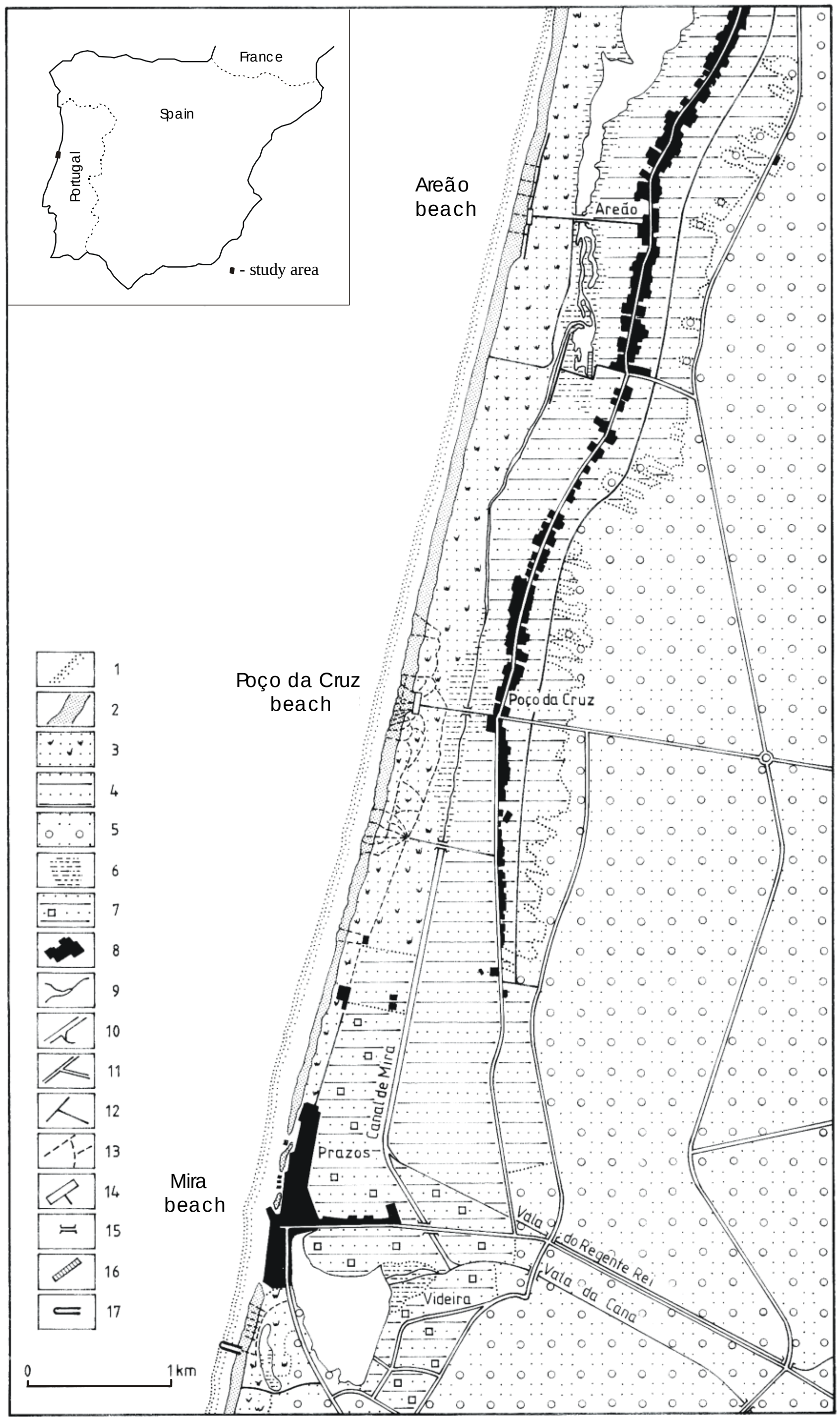
3. Application Example

In order to illustrate the applicability of the proposed resilience checklist, we chose the example of Mira's foredune system (between Areão beach and Mira's beach) in the western Portuguese coast (Fig.1). This system is part of a beach-foredune coastline, about 50km long, extending from Aveiro e to Quiaios (Serra da Boa Viagem). This coast has a very high energy wave climate, with a N-S dominant littoral drift. Several heavy coastal engineering structures updrift from Mira's foredune system have progressively turned this system a more vulnerable one to marine erosion.

The foredune is well developed, exceeding 5 meters high. At the northern sectors (as in Areão beach) the foredune is cliffed in a great extension. At Poço da Cruz beach and Mira's beach southern sector there is a high density of breaches and blowouts due to trampling. The foredune is locally destroyed by urbanisation and traditional fishery activities at Mira's beach northern sector.

Human pressure is highly variable in time and at each foredune site, mainly due to visitors and tourists dispersion along this particular coastline, during summer.

Figure 1 - Mira's study area



1 - beach; 2- foredune; 3 - brushwood (aeolian sand); 4 - agriculture (aeolian sand); 5 - forested dune field; 6 - salt marsh; 7 - rural area (aeolian sand); 8 - urban area (aeolian sand); 9 - lagoon and river; 10 - artificial banks; 11 - main road; 12 - secondary road; 13 - path; 14 - dock; 15 - bridge; 16 - parking lot; 17 - jetty

In the last decades, the studied coastal area has become increasingly attractive for regional scale recreation and tourism. This has led to an irregular and unmanaged path network spreading that promotes foredune degradation, particularly near urbanised areas. The natural conditions and human actions lead Boto (1997) to consider this coastline as a “high risk” one, very vulnerable to extreme spring tides, to ten years recurrence storms and to storm surge.

Such a situation justified a recent management effort from the municipal and regional authorities, in order to minimise the problem.

The studied site- Mira’s beach southern sector, contiguous to Mira’s urban beach-, is a site of great interest with respect to seaside recreation and tourism, therefore under a very high summer pressure. Three management phases were monitored, between 1996 and 1998:

a) First phase, before 1997

Beach sediment budget, more or less, stabilised since downdrift jetties were built, in the seventies, allowing the formation and maintenance of backshore embryo dunes.

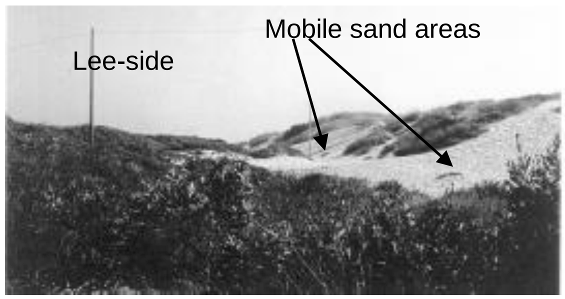
Fences (sand traps) have been installed for several years in a way to reconstruct the foredune ridge, close to the seaside urban wall built back in the 50's. This, and visitors trampling, have eventually led to the opening of a large blowout. Between winter 1996 and winter 1997, regeneration was very high: several alignments of fences were placed each time higher and a dune form is almost reconstructed (Photo 1).

Photo 1 - Dune regeneration induced by the installation of fences (sand traps)

14/03/1996 30/07/1998

Until 1997, an ineffective beach access management through the foredune ridge (distance between paths of 50m), failed to control disperse trampling and produced numerous bare sand accumulations at the leeside, which were already invading the inland brushwood (Photo 2). Therefore, the loss of sand inland from the system resulted in a negative foredune sediment budget.

Photo 2 – Sand accumulation at the leeside of the dune already invading the inland brushwood



26/07/1996

b) Second phase, between 1997 and 1998

Several sand traps (fences) were installed along the foredune's seaward face dunes (Photos 3 and 4). These traps restrained access from the sea-side and promoted a high development of embryo.

Photos 3 and 4 - Sand traps (fences) installed along the foredune's seaward face dunes

30/07/1998

30/07/1998

c) Third phase, summer of 1998

Fencing (sand traps) renewal along the recently developed embryo dunes and new fences installation at the leeside to promote sand trapping and restrict access from the inland-side (Photo

5). Some elevated walkways were simultaneously built, for a more effective trampling control (Photo 6). Despite all these measures, no dune revegetation program was implemented.

Photo 5 - Installation of fences at the leeside of the dune to promote sand trapping and restrict inland-side access

30/07/1998

Photo 6 - Elevated walkways built for trampling control

30/07/1998

Figure 2 shows the corresponding results of the resilience checklist application, for each phase. In the two first phases there were no significant changes in the natural conditions ("Dune erosion" and "Sand input defficiency"), but the vegetation has been progressively destroyed by human pressure ("Sand retention by vegetation" and "Use degradation") in the absence of adequate planning and management measures. These measures began to be implemented between 1997 and 1998. At first, the elevated walkways construction promoted a local degradation, with incise breaches were these walkways were built. But, a year later, the foredune exhibit a clear regeneration.

Figure 2 - The evolution of the foredune resilience in Mira's beach (south sector), between 1970 and 1988

	1970-1996				1996/1997				1998			
	N0	N1	N2	Σ %	N0	N1	N2	Σ %	N0	N1	N2	Σ %
Dune erosion	■				■				■			
	■			2	■			2	■			2
	■				■				■			
	■				■				■			
			■	20			■	20			■	20
Sand input		■				■			■			
			■	3			■	3			■	2
				75				75				50
Sand retention by vegetation		■				■				■		
		■		2		■		2		■		2
	■			33,3	■			33,3	■			33,3
Dune degradation by use		■				■			■			
	■				■						■	
		■			■				■			
	■				■				■			
	■				■				■			
		■		3		■		2		■		3
	■				■				■			
	■				■				■			
	■			16,7	■			11,1	■			16,7
Dune Management			■			■			■			
			■			■					■	
			■		■				■			
		■			■				■			
		■				■				■		
	■			17	■			10	■			6
	■				■				■			
			■				■		■			
			■				■				■	
			■				■		■			
			■		■				■			
		■		70,8		■		41,7		■		25
				Σ =43,7%				Σ=36,2%				Σ=29%

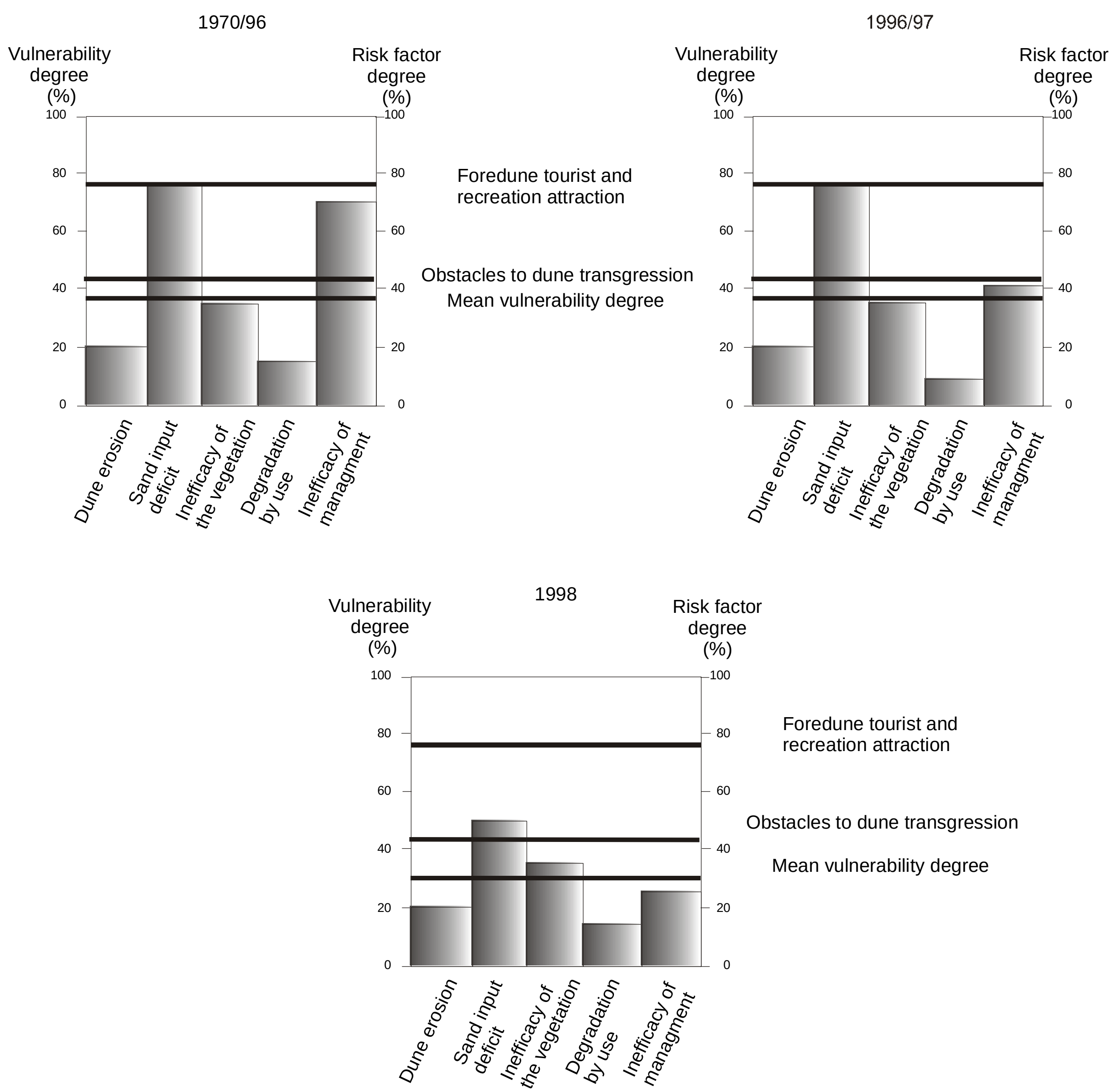
	G0	G1	G2	
Obstacles to dune transgression	■			
	■			
		■		
			■	Σ=3⇒42,8%

	P0	P1	P2	
Tourist and recreation attraction			■	
			■	
	■			
			■	Σ=6⇒75%

The resilience checklist results (Fig.2) show the dune management inefficiency and the ineffective sand retention by vegetation as determinants to Mira's beach southern sector vulnerability and also outline the fact that information boards and a planting program are still in need. Figure 2 also shows a clear decrease of the foredune vulnerability in this site.

Data in matrix (Fig.2) may be expressed and complemented in graph (Fig.3), relating all vulnerability descriptors with the mean degree of vulnerability (mean percentage of all descriptors

Figure 3 - The evolution from 1970 to 1998 of the descriptors values reported to mean vulnerability degree



vulnerability), and with the risk factors degree (tourist attraction and obstacles to dune transgression). The graphs show, in a simple and direct way, which components of the foredune system are more vulnerable and more in need of management measures implementation. Sand traps installation and access restriction promoted a high sand retention by vegetation and the growth of embryo dunes, as well as a significant decrease of sand loss from the foredune ("Sand input defficiency" from 75% to 50%), although the vegetation efficacy stayed the same. In fact, in absence of an adequate dune revegetation program until 1999 led to the maintenance of the same vulnerability degree of "Sand retention by vegetation" descriptor, during the studied period.

4. DISCUSSION

The resilience checklist method was developed from a different perspective of the root checklist ELOISE/DUNES, and was based on the resilience and carrying capacities of coastal dune systems, namely foredunes.

The application of the proposed checklist to a selected number of the Mira's foredune system sites, in W Portugal coast, showed that this method easily enables interpretation of the foredune dynamics. In fact, the high vulnerability components of the system were identified and the appropriate management measures to take in each studied site were pointed out. The results could be synthetized in graphs clearly showing the interactions between each vulnerability component and risk factors. On the other hand, the resilience checklist also enables the assessment of coastal dune sites from an economic, spatial and temporal perspective taking into account the system's tourist attraction and obstacles to dune transgression (considering a 50 years coastline retreat time horizon). Mira's foredune system is in an actual risk situation, where sand is already invading an inland urban area, and in a potential risk situation, where tourist attraction is very high.

The resilience checklist may prove to be more useful for managers, usually non-experts, for several reasons:

1) The checklist structure is organised in a way to enable dune managers to identify directly the components of the system that are more vulnerable and therefore those who need a more urgent management intervention;
2) The tree degrees of biophysical vulnerability enable to organise a checklist of critical vulnerability thresholds, which could be a more useful tool for management, particularly with environmental sustainability as a goal;

3) Dune vulnerability can be easily evaluated by direct observation of dune morphology, signs of damage and managed response;
4) It enables managers to assess coastal dune sites from an economic, spatial and temporal perspective;
5) It enables good regional comparison of foredune systems and gives essential information to dune management at the local scale.

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APPENDIX

COASTAL DUNE VULNERABILITY

Resilience checklist

A absence; P presence; N need; U unnecessary; CL coastline

Vulnerability descriptors and variables used			Vulnerability degree 0	1	2
Dune erosion	By marine erosion	Cliffed foredune as % of foredune lenght	A	P <50%	P >50%
		Dune cliff high as % of foredune	P <25%	P 25% - 50%	P >50%
		Recent overwash(es)	A		P
	By wind erosion and by man	Active breaches as % of foredune	A or poorly incised (<1m) in <50%	P poorly incised (<1m) in <50% or P incised breaches (>1m) in <50%	P incised breaches (>1m) and/or large breaches (>2m) in >50%
		Active *blowouts* as foredune area	A	P incipient blowouts as <1/3 or P main *blowout* as <1/3	P incipient blowouts as >1/3 or P large *blowout(s)* as >1/3
		Sand blow inland from the system	A	Small sand accumulations	Damage created by sand accumulation; intervention needed
Sand input		Embryo dunes windward as % of foredune	P >50%	P < 50%	A
		% of breaches with embryo dunes	P >50%	P<50%	A
		% of *blowouts* with embryo dunes	P >50%	P <50%	A
		Overwash(es) with embryo dunes	Partial reconstruction of dune ridge	Isolated embryo dunes	A
Sand retention by vegetation		% system surface unvegetated	<25%	25% - 75%	>75%
		% seaward face vegetated	>50%	10% 50%	<10%
		Damage state of seaward face vegetation	<25%	25% - 75%	>75%

Vulnerability descriptors and variables used			Vulnerability degree 0	1	2
Pressure of use / Degradation by use		Access beach path network density (F - path frequency/100m of seaward face)	Paths trough dune ridge at specific points (F≤ !)	High density paths trough dune ridge at specific points or diffuse path network (1≤ F≤4)	High density and diffuse paths trough dune ridge (F>4)
		Paths incision	Little (<1m)	Moderate (<2m)	Deep (>2m)
		On-dune driving	A	Some tracks	Much; diffused tracks
		Horse riding	A	Some tracks	Much; diffused tracks
		Commercial camping/foredune area	A	As <1/4	As >1/4
		On-dune urban areas or housing/foredune area	A	Isolated or disperse over <1/4	Disperse over >1/4 concentrate
		Sand extraction / foredune area	A	Causing destruction of <1/4	Causing destruction of >1/4
		Fishery activities	A or not causing significant degradation	Causing destruction of <1/4	Causing destruction of >1/4
		Sportive camps (green and others)	A	Partial occupation of foredune	Total occupation of foredune
Dune management	General measure	Managed path	All, elevated walkways	Partial, elevated walkways	A
		Information boards	P, well conceived and strategically placed	P, in bad condition, wrong conception or mis-placed	A
		On dune driving control	P and efficient or U	Insufficient (1)	A
		Horse riding controlled	P and efficient or U	Insufficient (1)	A
		Housing/construction controlled	P and efficient or U	Insufficient (1)	A
		Sand extraction controlled	P and efficient or U	Insufficient (1)	A
		Fishery activities controlled	P and efficient or U	Insufficient (1)	A
	Specific measure	Sand trapping	A or U or P all deflation areas	A or insufficient, but N <25% of foredune	A or insufficient, but N >25% of foredune
		Planting on mobile bare sand areas	A or U or P strategic areas for dune conservation (2)	A or insufficient, but N <25% of foredune	A or insufficient, but N >25% of foredune
		Beach or dune nourishment	U	P, with successful results	N or P, with successful results
		Restricted access	A or U or P in strategic areas	A or insufficient, but N <25% of foredune	A or insufficient, but N >25% of foredune
		Defence coastal engineering	A	P, downdrift jetties normal to CL	P, seawalls or updrift jetties normal to CL

(1) Signs of degradation and or/conservation laws not-efficiently applied.
(2) Areas where a vegetation planting program must implement sand retention and dune growth.

Risk factors and variables used		Degree of dune transgression limitation		
		0 (no limitation)	1 (partially limitation, increasing dune vulnerability	2 (total limitation, high dune vulnerability
Land use (1) **as obstacules to dune Transgression**	Natural areas	>75% brushwood	>75% forest	A or >50% agricultural
	Urban areas	A	>50% dispersed urban areas	>50% concentrated urban areas
	Other management areas	A	>50% sportive camps, camping, others	
	Roads	Unpaved roads	Secondary roads	Main roads, railway lines

Risk factors and variables used		Visitors pressure		
		0 (low)	1 (moderate, increasing dune vulnerability	2 (high, determining high dune vulnerability)
Recreation and tourism attraction	Level of tourism accommodation	A or rural setting	Moderate urban and rural setting (camping, hostels and low capacity holiday villages, low number of summer homes	High level of urban and rural tourism accommodation (all forms of high capacity tourist accommodation, high number of summer homes)
	Road access and parking	A or bad	Reasonable	Good
	Leisure areas	A	P, but in bad conditions	P and in good conditions
	Development level of seaside recreational activities	Beach in natural setting; without development	Beach in rural setting with low development (including lifeguard and refreshments / restaurants)	Beach in urban setting with high development (including lifeguard, sunshades, sanitary and shower facilities, refreshments/restaurants, open games and sports facilities and equipment storage)

(1) Inland width area depends on retreat rate in the last 50 years.