1. Introduction

The United Nations Convention to Combat Desertification (UNCCD), adopted in Paris on 17 June 1994, includes the following definitions:

- "desertification" means land degradation in arid, semi-arid and dry subhumid areas resulting from various factors, including climatic variations and human activities;
- "combating desertification" includes activities which are part of the integrated development of land in arid, semi-arid and dry subhumid areas for sustainable development which are aimed at:
  - prevention and/or reduction of land degradation;
  - rehabilitation of partly degraded land;
  - reclamation of desertified land.

Mauritania is one of the Sahelian countries most severely affected by the periods of drought that have been occurring since 1968. The resulting desertification is exacerbated by human activities, which have compounded climatic factors, with direct consequences for an already precarious situation – bringing about degradation of the environment and the general socio-economic conditions of the country, and the progressive impoverishment of a population that is 70 percent rural.

The main effect of desertification has been a reduction in the amount of arable land, grazing land, forests and water resources. Various studies show that mobile sand dunes today cover two-thirds of the country's land area.

The devastating effects of desertification and drought on agricultural productivity and yields have resulted in:

- endangerment of rural inhabitants' food security and standard of living;
- large-scale movements of people toward major urban centres;

Sand encroachment threatening the town of Nouakchott

- reduced water supplies for human and livestock needs;
- substantial economic losses.

In view of the extent of the phenomenon, Mauritania, like many other countries affected by drought and desertification, has expressed a firm political will to combat this scourge.

It was in this context that the Sahel Club and the Permanent Inter-State Committee for Drought Control in the Sahel (CILSS) were established. In 1980, CILSS designed a drought control and development strategy for the countries of the Sahel, with the two main objectives of bringing about food self-sufficiency and environmental balance. However, implementation of the strategy did not have the anticipated results because of the complexity of the desertification problem. Recognizing this failure, the Mauritanian Government decided to incorporate desertification control into an overall process of sustainable development of the country, encompassing technical, socio-economic, juridical and institutional factors, a decision leading to:

- formulation of a Desertification Control Master Plan (PDLCD);
- formulation of a Multisectoral Desertification Control Programme (PMLCD);
- formulation of a National Action Plan to Combat Desertification (PAN-LCD);
- formulation of a National Action Plan for the Environment (PANE).

Within this framework, national-level programmes and projects have been implemented with the support of development partners in order to foster conservation and agrosilvopastoral development and combat sand encroachment. These programmes and projects include:

- the Nouakchott Green Belt Project, financed by the Lutheran World Federation (LWF);
- the Sand Dune Stabilization and Fixation Project, financed by the United Nations Development Programme (UNDP), the Danish International Development Agency (DANIDA) and the United Nations Sudano-Sahelian Office (UNSO);
- the Sand Encroachment Control and Agrosilvopastoral Development Project (PLEMVASP), also financed by UNDP, DANIDA and UNSO;
- the Oasis Development Project, financed by the International Fund for Agricultural Development (IFAD) and the Arab Fund for Economic and Social Development (AFESD);
- the Kaedi Green Belt Project, financed by the European Union;
- the Integrated Natural Resource Management in East Mauritania Project, financed by the German Agency for Technical Cooperation (GTZ);
- the Support for the Rehabilitation and Extension of the Nouakchott Green Belt Project, with financing from the Walloon Region of Belgium and the support of Prince Laurent of Belgium.

2. Understanding sand encroachment

Sand encroachment is said to take place when grains of sand are carried by winds and collect on the coast, along water courses and on cultivated or uncultivated land.

As the accumulations of sand (dunes) move, they bury villages, roads, oases, crops, market gardens, irrigation channels and dams, thus causing major material and socio-economic damage. Desertification control programmes must then be implemented in order to counter this very serious situation.

Before designing such programmes, information is needed about the factors and processes fostering the formation and movement of sand masses, i.e. wind and soil.

WIND EROSION

The main causes of wind erosion are:

- a violent wind blowing over large areas;
- stunted or sparse vegetation;
- a degraded soil that is mobile, bare and dry.

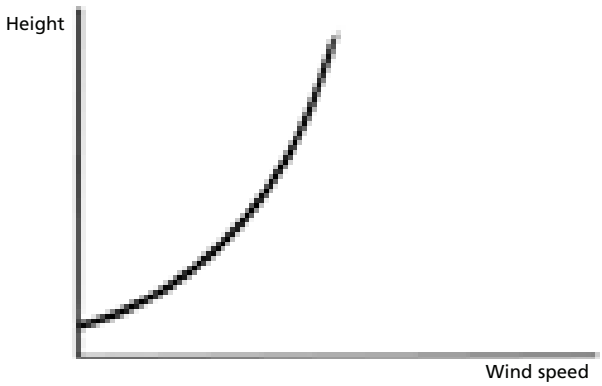
Violence of wind

The first factor affecting the displacement of soil particles is the direction, speed and duration of the wind. When a wind blows predominantly from one direction, it is known as a prevailing wind. Wind speed is zero at ground level, but increases in force the higher it is from the surface of the ground, its speed increasing as the logarithm of height (Figure 1).

A wind cannot lift sand particles off the ground until its speed at 30 cm above ground level, measured with an anemometer, is at least 6 m per second. Wind speed is an essential factor, for it determines the force of sand removal. The greater is the speed, the greater the carrying capacity.

The second factor is the size and density of sand particles. Particles with a diameter of about 0.1 mm are the first to be removed, whereas a violent wind is needed to remove larger particles.

FIGURE 1
Wind speed in function of altitude



Curve S = f(h), according to Henin

Source: Henin *et al.*, 1960

The nature of the movement of particles varies depending on their size (Figure 2):

- The largest particles roll or slide along the ground in a mechanism known as reptation or creep. The grains of sand that move in this way are between 0.5 and 2 mm in diameter depending on their density and the wind speed. When they start to travel more slowly because of the braking effect of the sand mass, the saltation mechanism becomes possible.
- Medium-sized (0.5 to 1.1 mm diameter) particles move forward in successive bounds, in a mechanism known as saltation. After leaping into the air, these particles fall back to the ground under the effect of weight; 90 percent of them reach a height of no more than 30 cm, moving on average between 0.5 and 1 m along the ground. The saltation mechanism is of vital importance in triggering wind erosion.
- Very fine particles, with a diameter of 5 microns or less, are shot into the air in the form of dust by the impact of larger grains. These particles then remain suspended and may be carried a long way in the form of a dust cloud, which often reaches an altitude of 3 000 to 4 000 m.

General mechanisms involved

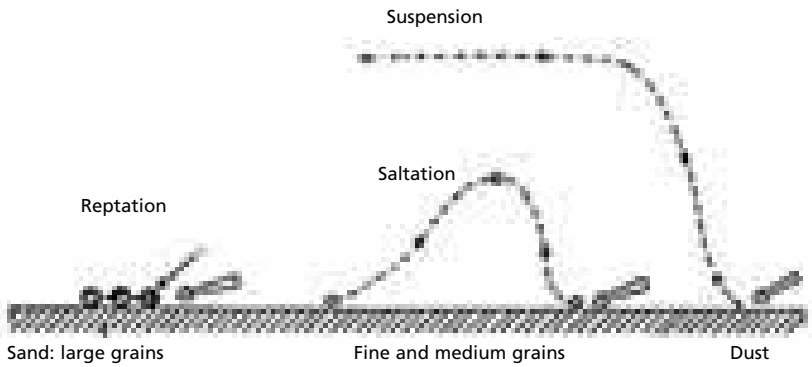
Particles in movement are the site of various interactions, the main ones being the avalanche effect, sorting and corrosion.

The avalanche effect is the result of saltation. As the grains of sand fall back, they cause the displacement of a larger quantity of particles, so that the more intense the saltation process caused by the wind, the greater the number of particles set in motion, until a maximum or saturation point is reached, where the quantity lost is equal to the quantity gained at any given moment. The distance needed to reach this saturation point will depend on the sensitivity of a soil to erosion: on a very fragile soil, it can occur over a distance of about 50 m, whereas it will require more than 1 000 m on a really cohesive soil.

The sorting mechanism concerns the wind's displacement of the finest and lightest particles, leaving behind the larger particles. This process gradually impoverishes the soil, since the organic matter made up of small light elements is the first to be removed.

Corrosion is the mechanical attack on the surface as the sand-laden wind blows over it. In arid regions, it is the aggravating cause of soil erosion and is seen in parallel streaks or the polishing of rocks.

FIGURE 2
Ways in which particles are carried by the wind



Source: Lemoine, 1996

State of vegetation

Vegetation preserves the cohesion of the surface layer of soil, retains particles, resists the avalanche effect and is the best protection against the negative effects of wind. This is why wind erosion is such a threat in arid and semi-arid regions where natural vegetation (whether woodland, bushland or grassland) is sparse, stunted or non-existent and where rainfall is low and irregular.

Moreover, unsustainable harvesting of such slow-growing stands leads to rapid degradation of the soil, which lacks protection and is therefore subject to the action of the wind.

Nature and state of soil

Wind erosion is the result of the wind's attacking the soil. Such erosion takes place if the soil has the following characteristics:

- mobile, dry and finely crushed (coarse-textured, rich in fine sand, poor in clay and organic matter);
- a uniform surface with no natural or artificial obstacles;
- sparse or non-existent plant cover;
- covering a sufficiently large area lying in the direction of the wind.

Soil that has been dried out over a long period is found especially in arid and semi-arid zones.

The soil's susceptibility to erosion can be exacerbated by poor farming practices (clearing of large areas), poor pastoral practices (overgrazing, with loosening and powdering of the soil) and unsustainable harvesting of forests, all of which make it extremely vulnerable to the action of the wind.

In Mauritania, soil is generally deep, fragile and predominantly sandy, and is for the most part located in zones with an annual rainfall of less than 100 mm.

ORIGIN OF SAND

When sand is carried by sea currents and accumulates along the shoreline in substantial quantities, it forms coastal dunes.

If it comes from the hinterland, it forms inland dunes, in which case the sand is either non-indigenous, coming from a considerable distance and having particles with a diameter of less than 0.05 mm, or indigenous, being of local origin and coming from the decomposition of mountain rocks (sandstone), the disaggregation of alluvial soil following the disappearance of plant cover, or from silt carried down by wadis following water erosion of their catchment basins.

For a long time, sand encroachment in Mauritania was considered a consequence of material carried from both near and far. However, according to Raunet (1985) and Khatteli (1989), non-indigenous material is insignificant compared with indigenous material.

EFFECTS OF WIND EROSION

On soil

The wind first carries off the finer parts of the soil – alluvium, fine sand and organic matter – thus weakening the soil structure. As the soil becomes sandier, it is more vulnerable to the wind and has a reduced water retention capacity. Its colour turns from grey to white and then to red as it is scoured. The terrain is gradually broken up by the creation of small mounds surrounding the woody and grassy vegetation as this degrades. The land gradually becomes unsuitable for cultivation.

On vegetation

The wind has both mechanical and physiological efforts on vegetation.

- ***Mechanical effects.*** The soil particles that are carried off collide with stalks and leaves with a force that abrades their tissue. In the zones from which the particles

are carried off, roots are uncovered and the vegetation risks being uprooted, while in zones where the particles are deposited the vegetation is steadily buried.

- ***Physiological effects.*** The wind increases evaporation and dries out plants, mainly in the dry season. The air's evaporating power is proportional to the square root of the wind speed. Moreover, the soil's water retention capacity is reduced, leading to water stress. The surrounding or moving mass of dry air tends to absorb humidity and exacerbate the water deficit – and this deficit is the main factor determining local vegetation, inasmuch as the latter has to adapt to the severe shortage of water.

WIND-BORNE ACCUMULATIONS

When the wind grows lighter, it loses its capacity to carry sand particles, which are then dropped. Forms of sandy accumulation vary widely, depending on landform, the nature of the soil on which they encroach, the presence or lack of vegetation, and the size of the grains of sand.

The main forms of accumulation found in Mauritania are wind veils, nebkas, barchans, linear dunes, sand ridges, pyramidal dunes, aklés and ergs.

Wind veils

Sand particles are carried over hard, flat, uniform surfaces, forming sandy veils of varying thicknesses, which are a constant threat to villages, roads, railways and irrigation channels. This type of wind accumulation is the source of the surface sand encroachment found almost everywhere in the country, which becomes particularly serious following clearing, forest fires and overgrazing.

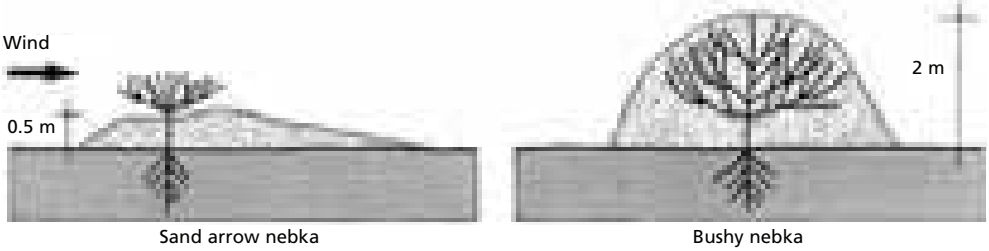
Nebka dunes

These accumulations are caused by the presence of a rock, plant or other obstacle in the path of sand particles in movement. There are two types of nebka: sand arrow nebkas, which are small ovoid dunes (50 cm in height, 150 cm in length and 40 cm in breadth) lying in the direction of the prevailing wind; and bushy nebkas, similar to sand arrow nebkas, but capable of reaching a height of 2 m and a length of 3 to 4 m (Figure 3).

Barchans

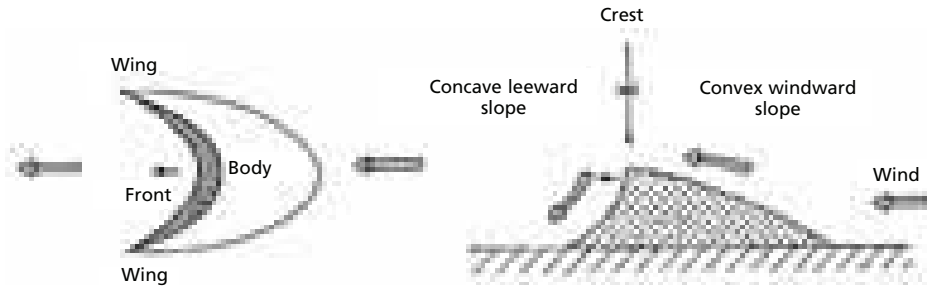
These are huge crescent-shaped dunes convex to the wind (Figure 4). There are several stages in their formation: they start as sandy shields, then turn into barchanic shields, then barchanic dihedrons, and finally full-scale barchans. Barchans tend not to remain isolated, but can join up and form complexes ranging from train-like successions of barchans to real dune massifs.

FIGURE 3
Nebkas



Source: FAO, 1988

FIGURE 4
Barchans



Source: Rochette, 1989

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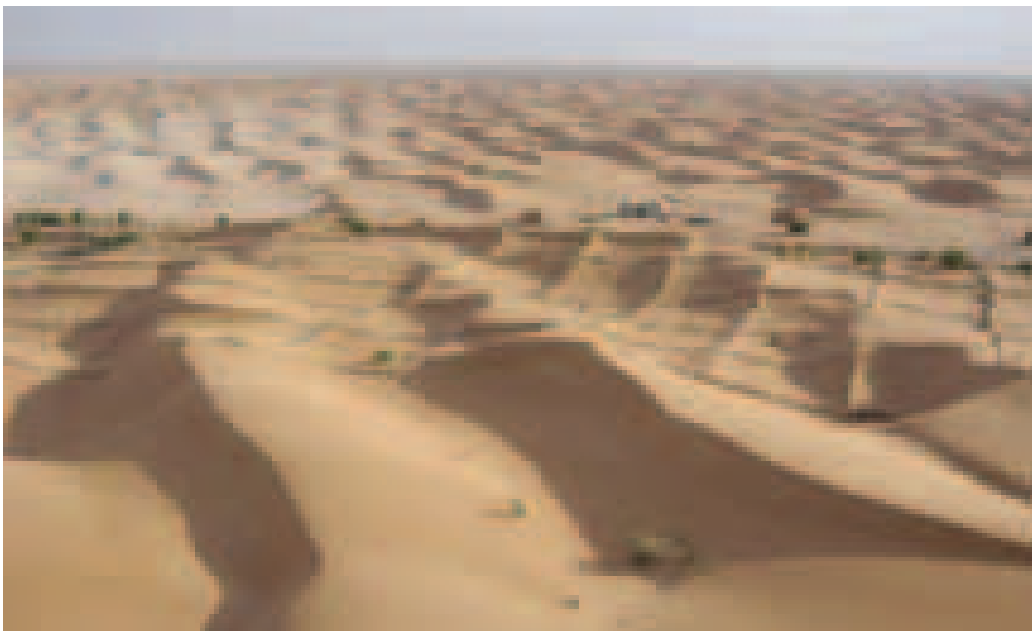
Isolated barchans



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Barchanic field or collection of barchans

Three conditions are needed for barchans to move: a constant wind from one direction, a large source of sand with grains of 0.12 to 0.25 mm in diameter, and a hard, flat surface. Inasmuch as barchans are unstable, mobile constructions that are constantly being remodelled by the wind, they can move several dozen metres per year.

Linear or sif dunes

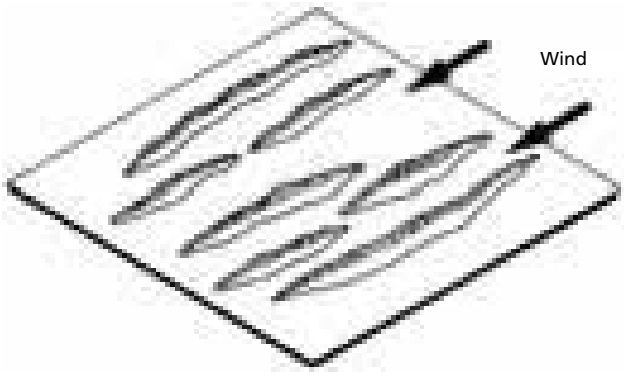
Linear dunes are elongated accumulations of sand, drawn out lengthwise like swords (*sif* in Arabic) (Figure 5). They are always eight to ten times longer than they are wide – on average 1 to 2 km long and 50 to 200 m wide. They sometimes gather together in formations that can reach 20 to 40 km in length, like those found alongside the Road of Hope.

This type of wind accumulation occurs in an arid environment with prevailing winds from two directions (northeast and southwest, for example) or a single prevailing wind with air flows that have been split up by irregularities in the terrain. These dunes lie obliquely to the average direction of the prevailing winds. The movement of a linear dune takes place through lengthening as new wind-borne sand is added.

Sand ridges

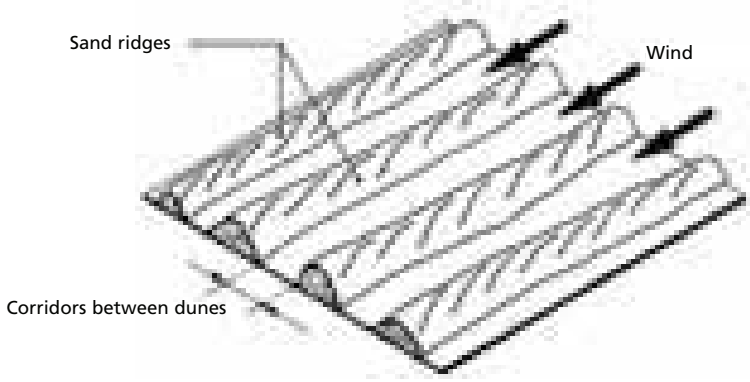
These ridges are large, broad sandy mounds, running lengthwise, side by side and separated by deflation corridors (Figure 6). They are fairly stable and do not move much. They lie in the direction of the prevailing winds, unlike linear dunes, which are

FIGURE 5
Linear dunes



Source: FAO, 1988

FIGURE 6
Sand ridges



Source: FAO, 1988

oblique to the average annual direction. Destabilization of these ridges is linked to the disappearance of woody and grassy cover. This type of formation can be seen on either side of the Road of Hope, with ridges running from northeast to southwest.

Pyramidal or ghourd dunes

Pyramidal dunes are hills of sand, often star-shaped, and can reach several hundred metres in height (Figure 7). They are the result of a convergence of various flows of wind and are basically stable and immobile. They thus become the source of sand that can give rise to barchans or linear dunes, as in the *wilayas* (administrative districts) of Tangant and Adrar.

Aklé dunes

This type of formation is found in the Inchiri and Adrar *wilayas*, and is a complex of overlapping dunes (Figure 8).

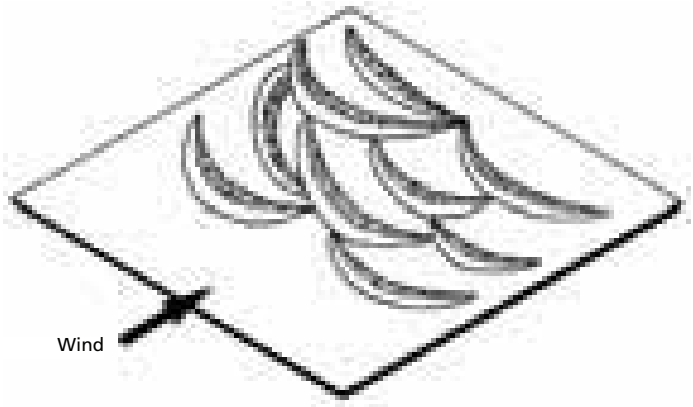
Ergs

Ergs are vast areas covered by dunes. This type of formation is very old (15 000 to 20 000 years) and stable. It presents no danger to urban areas, roads or crops.

FIGURE 7
Pyramidal dune

Source: FAO, 1988

FIGURE 8
Aklé dune



Source: FAO, 1988

IDENTIFICATION OF SANDED-OVER SITES

Field observation

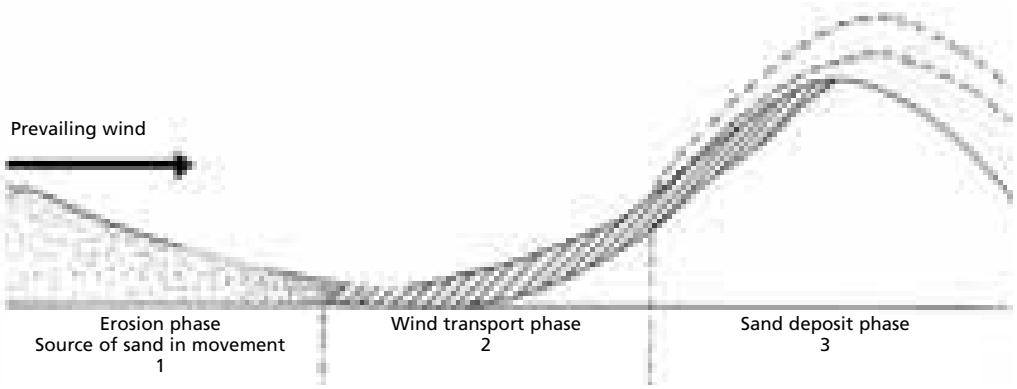
When a site is threatened by sand encroachment, the sources of sand, the transport zones and the accumulation sectors must be carefully identified (Figure 9).

The sources of sand may be local or mixed (indigenous or non-indigenous). Sand may also come from the degradation of plant cover, old dunes that have been reset in motion, or current matter coming from flood spreading, alluvial terraces or wadis. When the precise location and extent of sand sources have been properly identified, it is then possible to define the best stabilization techniques to be adopted.

Transport zones are the areas over which sand moves through saltation and rolling, leaving such traces of its passage as wind veils and nebkas. The direction of these traces indicates the direction in which sand is being moved toward deposit zones.

Accumulation sectors or deposit zones are major sand masses, such as barchans, linear dunes and sand ridges, which are a threat to villages, roads, market gardens and palm groves. These masses are turned into dune fronts when they encounter an obstacle in their path. The crests of these fronts mean that they constitute sand traps, which can reach a height of several metres and are capable of burying everything as they move forward. Accumulation sectors also constitute major masses of sandy matter that can be carried off by the wind and overrun other sites.

FIGURE 9
Dynamics of sand encroachment



Source: FAO, 1988

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Deflation and transport zone

Mapping of sanded-over zones

Sanded-over zones must be surveyed and mapped, with precise geographical coordinates. Studies will indicate the directions of sand encroachment, the location of sand deposit sectors and appropriate types of treatment.

In Mauritania, all the sanded-over sites in the various *wilayas* were surveyed and recorded in 1990 on a general map of the Multisectoral Desertification Control Programme (PMLCD). These data are available from the Directorate of Nature Protection of the Ministry of the Environment and Sustainable Development.

TYPES OF TREATMENT

With a view to fixing mobile dunes, it is necessary to study the composition and characteristics of the sand, the strength, frequency and direction of the wind, the quantity, duration and frequency of rainfall, and the existence or lack of natural plant cover on the dunes.

The fundamental principle of dune fixation is that of preventing sand from moving during a long enough period to allow natural or planted vegetation to become established. If sand encroachment is to be controlled, saltation must be reduced, either by stabilizing the soil or by reducing the wind speed gradient close to the surface of the ground. Wind speed can also be used in techniques to manage sand and dune masses, for when the wind moves fast it removes sand, thus clearing sanded-over sites. On the other hand, when its speed decreases, it drops sand. On the basis of these general principles, two types of fixation can be distinguished.

Primary fixation entails either the mechanical stabilization of sand masses by slowing their speed and movement or preventing the formation of such masses through:

- installation of palisades or fences and wattling perpendicular to the prevailing wind;
- spreading of material that can cover the soil in a uniform manner (mulching);
- shaping of the obstacle in order to maintain or increase the wind speed, a technique that increases the sand mobilization and transport capacity.

Definitive or biological fixation is done by installing and protecting a permanent woody and/or grassy plant cover (sod seeding or direct sowing, fencing off, permanent posting of guards).