CASE STUDY

Coastal Protection of the Leirosa Sand Dunes System

ABSTRACT

The implantation of a submarine outfall pipe in 1995 for the cellulose pulp and paper companies Celbi and Soporcel, lead to some changes in the Leirosa sand dunes system. The use of hard machinery and the nearby presence of a breakwater increased the lasting problems of erosion in this coastal ecosystem.

Sand accretion was the first step to the reconstruction of the Leirosa dunes (which started in 2000). After that, to stabilize the sand, revegetation was carried out with transplants of the grass *Ammophila arenaria* (L.) Link, the most appropriate plant species used in these situations.

The winter of 2000/2001 was particularly severe and in February 2001 most of the oceanic side of the Leirosa rehabilitated sand dune system was destroyed. The monitoring plan continued, to assess sand erosion and vegetation growth.

In February 2005, after evaluating several alternatives, the Leirosa sand dunes were reconstructed with layers of geotextiles filled with sand. Once the sand containers were in place, this protection barrier was covered by a 1 m layer of sand which was planted with *A. arenaria*, turning this area into an attractive and safe coastal dune system.

Some problems, probably caused by unapropriate seal of the geotextiles layers, lead to their opening in some parts of the 3 bottom layers in March 2006. In order to stabilize and reinforce the sand dune in this specific damaged area, a proposal of rehabilitation including geotextiles tubes is currently being analysed.

A protocol involving two industries, Celbi and Soporcel, and the IMAR research Institute, was established already in the year 1999, to promote the sustainable rehabilitation of the Leirosa dune system. It follows a brief presentation of this successful collaboration.

LOCATION

Leirosa, Portugal

KEYWORDS

Sand dunes; Rehabilitation; Coastal Protection; Erosion; Monitoring; Revegetation; *Ammophila arenaria*; Geotextiles; Leirosa, Figueira da Foz, Portugal

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INTRODUCTION

During 1995 and after formal authorization of INAG, the Portuguese Water Institute and official licenser for those matters, cellulose pulp and paper companies Celbi and Soporcel built up a submarine outfall pipe to discharge, after proper treatment, their industrial liquid effluents in the Atlantic Ocean, 1,5 km far from the coast, to the south of Leirosa, Figueira da Foz, Portugal.

The works to install the land pipeline had to cross the sand dune, which was open at an extension of 80 meters, using hard machinery. After the outfall pipe installation, the dune has been rebuilt with the original profile, strictly according to the licensing conditions, using only compacted sand over an inner cord of rocks.

When the submarine outfall pipe entered into service at middle of August, 1995, cellulose companies started a thorough monitoring program to survey the quality of beach waters from the zone of effluent's discharge influence on the sea, to follow up physical, chemical and microbiological parameters as well as fish population condition. In parallel the local dune has been closely surveyed, providing that it is well known the severe coastal erosion occurred during the near past years, which stresses not only the Leirosa beach, but all the coast line at the south of Figueira da Foz harbour. At that place the dune is the natural protection for the deaeration and load chamber of the outfall pipe, located quite close to the continental side of the dune, that is an important piece of the hydraulic system to allow that natural discharge of effluents can work properly.

After a couple of years, it was noticed a big change of the protection dune profile and a dramatic regression along the beach, mainly due to the existence of a breakwater located close to 1 km north, which causes the retention of large amounts of sand north-side of it, and a natural increase of erosion problems at the south-side. By the end of 1999 the protection dune was almost broken and flat, and it was decided to look for technical support from specialists to repair such damages, in order to preserve the integrity of the deaeration chamber.

Figure 1 – Leirosa sand dunes system, February 2000

DUNE REHABILITATION

The rehabilitation of the Leirosa sand dunes started in March 2000, by a process which allows the mechanical reestablishment of the dune until the desired height and sloping in a shorter time, known as AIDS – Artificially Inseminated Dune System (Carter, 1995). For three weeks sand was brought from a close inland site and the foredune of the Leirosa system was rebuilt in an extension of about 200 m, in front of the deaeration chamber of the outfall pipe. The sand used in the reconstruction of the dune was very similar to the existing on the dunes in terms of texture and nutrients' content.

To assist the erosion control, but essentially to avoid traffic and people crossing in the recently shaped dune, a wooden fence was built around the restored area. A walkover with stairs was also constructed to allow people to access the beach. The fence was made from pine planks with 1m height and 8 cm width, placed 8 cm apart from each other to create the 50% porosity, which is advised in these situations (Dewhurst, 1999).

Figure 2 – Leirosa sand dunes system, March 2000

REVEGETATION

After reconstruction of the Leirosa dunes system, in order to stabilize the sand, revegetation was performed with transplants of *Ammophila arenaria* (L.) Link, the most common grass used in these situations, as it is easy to collect, transplant and rapidly propagate (van der Putten, 1990). This grass plays an important role in the dune ecosystems, especially in the foredune where it is the dominant plant in almost all the European and North African coast (Huiskes, 1979). The protection of coastal erosion through the formation of dunes and sand stabilization played by *A. arenaria* is mainly due to its interface and complex root and rhizome system, which makes this species the most appropriate and commonly used in recovery works and even dune formation (van der Laan *et al.*, 1997).

Dune vegetation is used to stabilize and even create sand dunes (van der Laan *et al.*, 1997) and it is considered the most appropriate, durable and effective as well as cheaper process of dune systems rehabilitation (Carter, 1995; Olafson, 1997). Since in Europe it is not common to have dune plants commercially available, revegetation has to be done using transplants from other dune systems.

In this work, plants used as transplants were taken from well preserved and close dune systems (from Osso da Baleia, some kilometres south of Leirosa), as similar conditions make easier the adaptation of the plants (Dewurhst, 1999). Plants were collected manually, using vertical spades to gather as much roots as possible. A dispersed pattern was used, removing individually plants at intervals not closer than 50 cm, so that a minimum impact was caused in the system.

Plants were collected in the morning and stored in large plastic bags with wet sand in the bottom. The transplant in the Leirosa dune was done every afternoon, so that plants wouldn't stay overnight. With small shovels, holes of about 20 cm depth were made and, after adding a very small amount of fertilizer, one or two shoots of *Ammophila arenaria*, were dibbled. Since the slope of the dune was rather steep, a close pattern of 50 cm in diagonal grid was chosen for the revegetation. The transplants were only placed where no other vegetation previously existed. No more than 100 Kg/ha of the slower released grain fertilizer "Osmocote" was used, as most appropriate in these works (Seliskar, 1995).

Figure 3 – Leirosa sand dunes system, April and May 2000

Revegetation started in the last week of April and went on for 5 weeks. Even though the best time of the year to do this work is usually the beginning of the Autumn or Spring, as factors like temperature and humidity have strong influence to the success of it, and the Spring of 2000 was characterized by heavy rain in March and April, which made the soil rather humid, a great advantage to the transplants´ adaptation. In the Leirosa dune system the combined revegetation of adjacent areas was also performed, in an attempt to recover the complete system.

FIRST MONITORING PHASE

In June 2000, after the rehabilitation work in the Leirosa dune, the monitoring programme started by characterizing, quantifying, locating and identifying the existing and the planted vegetation. The restored area was divided in continental and oceanic sides, mainly to determine the efficiency of plant recover in both sides of the foredune. Graduated wooden poles were also placed all over the Leirosa dune to measure sand mobility. The first monitoring period was conducted monthly from May to September 2000. Twenty transects perpendicular to the coast were established and the number of individual transplants of *Ammophila arenaria* was counted and classified as dry or green, and if flowering or not (Schreck Reis & Freitas, 2000).

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A total of 23250 transplants of *A. arenaria* were planted in Leirosa, 17200 in the continental side and the remainder in the oceanic side. After 4 months, a survival rate of 40% was observed, which can be considered a significant high percentage (Dewurhst, 1999). During summer months a decrease of the number of green plants was verified, most probably due to the hot weather, as in September it happens that such number began to raise, indicating that plants were not dead but just dried up due to transplant and weather conditions.

Although the transplantation occurred in April and May, many of the plants brought to the Leirosa dune were already starting to flower and others started later in that same year, reaching 63.5% and 50.0% in the oceanic and continental sides, respectively. The reconstruction of the foredune allowed a stabilized ecosystem in the back, favoured by the almost inexistent sand mobility. A similar situation did not occur in the oceanic side, where a significant sand accumulation was found during the first phase of the monitoring programme.

Figure 4 – Leirosa sand dunes system, from May to September 2000

DUNE RUINATION

The winter of 2000/2001 was particularly severe, with strong wind and uncommon heavy precipitation, causing huge damages in the Baixo Mondego region and also on the coast. Most of the coastal region was affected, although the effects were largely seen at the south of the breakwater of the Leirosa village, an area already facing strong erosion problems. In February 2001, the oceanic side of the rehabilitated sand dune of Leirosa was destroyed. All the vegetation transplants from that side were lost, and an enormous amount of sand was taken by the sea. The fence placed on the top of the foredune also disappeared. The continental side was already well stabilized and did not suffer with the storm.

Figure 5 – Leirosa sand dunes system, February and March 2001

The industries involved in this project have decided to pursue the monitoring plan in March 2001, after the partial destruction of the foredune in February.

SECOND MONITORING PHASE

A second monitoring period started in March 2001 and lasted about one year, focused on the continental area (Schreck Reis & Freitas, 2002).

This time, 12 plots of about 4 m^2 were established, to identify all plant species and to estimate total cover. The plots were located by the wooden graduated poles for sand mobility measurements that were still undamaged. After the partial destruction of the foredune, a significant increase of sand in the back of the dune from less than 1 cm to an average of 4.6 cm was observed, but it stabilized again in a few months. In the oceanic side, this assessment was not possible as all the graduated poles were removed by the sea. Thirteen species were found in March 2001, including *Ammophila arenaria*. Due to the revegetation that created a stabilized dune and also to the fertilizer input (that raised the percentage of organic content in the sand from 0.25±0.013 to 0.33±0.014 in only 3 months), the number of species found in March 2002, even after the storm, was 32. In the second monitoring period, plant cover was estimated in the established plots and it was surprising to notice an average cover of 42.8%. This is a significant high value taking into consideration that revegetation was concluded only one year before, and that a storm destroyed part of the rehabilitated dune.

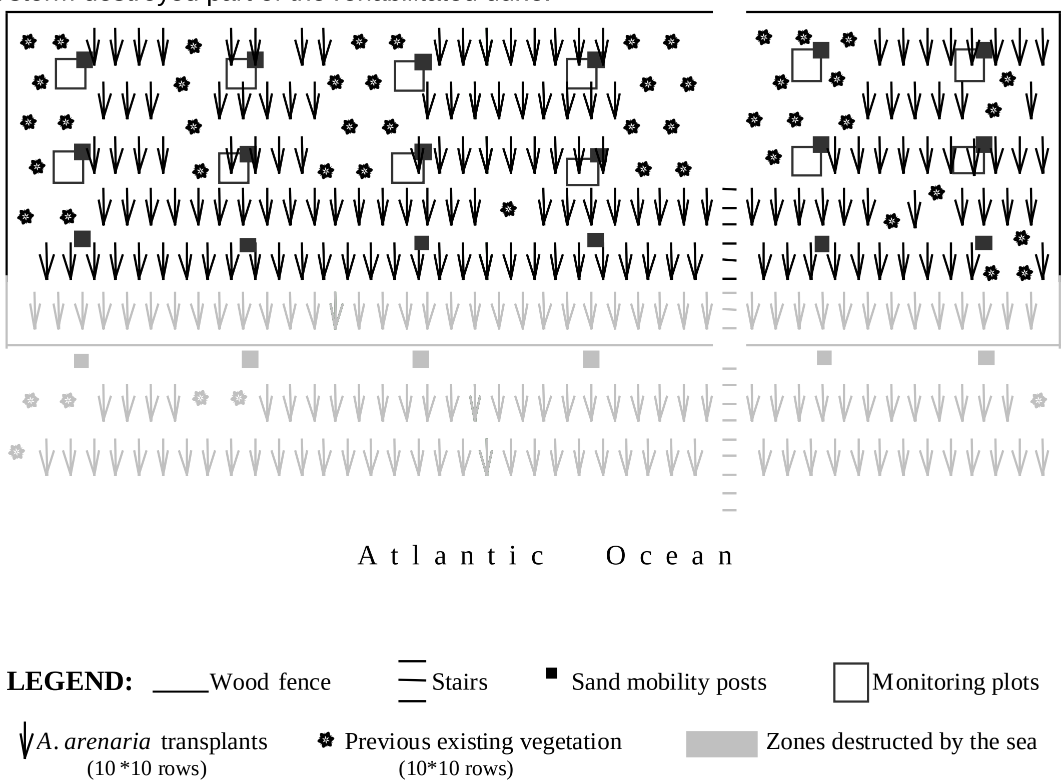

Figure 6 - Schematic representation of the rehabilitated area of the Leirosa dune system

In the summer of the second year of the monitoring plan, seeds from the most representative species were collected from the surrounding area of the rehabilitated dune, and in the spring of 2002 they were sown in places where plant cover was smaller, and where the transplants of *A. arenaria* were clearly decaying.

Figure 7 – Leirosa sand dune system, from March 2001 to January 2005

APPLICATION OF GEOTEXTILES

In February 2005, after analysing several proposals of dune rehabilitation by soft and hard engineering, a new intervention in the Leirosa sand dune system was conducted. The decision was based upon the potential efficiency of the technical solution selected, but also costs involved and time required to implement it. Geosynthetic containers filled with sand are playing more and more a relevant role, all around the world, in the construction of coastal and marine structures. Traditional construction techniques using rock, concrete and steel are being increasingly challenged by alternatives offered by geosynthetic forms for revetments, scour protection, groynes, berms, artificial reefs, reclamation and dune stabilization, to name but a few uses. Furthermore, improvements in materials, design and construction methods for such structures are enhancing and diversifying the range of possibilities and applications (Antunes do Carmo *et al*., 2006). Geotextiles have been successfully used in hydraulic engineering and more recently also in the construction of artificial dunes and stabilisation of beach nourishment measurements. It is shown that the use of geotextiles can be as effective as any so called "hard engineering protection", with the advantage of being adaptable to the morphology of the dune system, and using locally available sand (Bleck *et al*., 2003).

In the Leirosa system the application of geotextiles occurred in a dune extension of 120 m along the coast. A defence was created on the front bottom of the dune, at the +2.0 level (hydrographic zero) with sand containers about 6.40 m long, 3.20 m width and 0.825 m height, placed in a pyramidal position parallel to the coastline. The protection barrier was constructed to the height of 8 m by several layers of sand involved in geotextiles, a so called "wrap around technique", which encapsulates the sand and offers a high installation speed. The upper layer has a geotextile revetment in all the area, with about 8.60 m length, 4.30 m width and 1.10 m height, followed by a 1.0 m layer of sand where dune vegetation is planted, turning this area in an attractive and safe coastal dune system.

In a situation of storm, the geotextile wrap has to absorb the energy of upcoming wave attacks and prevents erosion of the fill material due to the tensile forces which are activated due to this stress. Secondly, pore water pressures within the encapsulated sand fill are released due to the good drainage capacity of the geotextile. To our knowledge, this new technique was used for the first time in the Portuguese dune protection, and it can be an important model to be applied in other dune systems with similar erosion problems.

The wave height required to obtain the dimensions of the sand containers was found after various statistical studies based on observations and data collected by the Portuguese Hydrographic Institute and by the ex-Autonomous Board of Figueira da Foz port. Various typical situations were considered and tested. The resulting sinusoidal waves were considered as input boundary conditions for a suitable numerical model, based on Boussinesq type equations (Antunes do Carmo *et al*., 1993), at a distance of 1450 m from the existing sand dune base, and in a region where the water column is about 14.5 m deep (intermediate water conditions). The results for the main relevant conditions, which represent characteristic situations of calms and storms over a 2002 bathymetry, are presented in Schreck Reis *et al*., 2005.

The maximum wave height close to the dune, without any protection, was found to be 2.5 m (Schreck Reis *et al*., 2005). Considering this wave amplitude value, the dimensions of the sand containers have been determined. Empirical expressions have been employed, according to the experimental work conducted for geotextile sand containers in the Large Wave Flume of the German Coastal Research Center (Bleck *et al*., 2003). Taking into account the scheme and notations presented in Figure 8, the following recommendations have been deduced for the required sand containers length at the front of the dune and at the crest, respectively.

a) Sand container length l_f (m) at the front

$$l_f = \frac{H_s^{3/4} \times T_p^{1/2}}{1.74 \times (\rho_E / \rho_W - 1) \times \sqrt{sen\,(2\alpha)}} \qquad (1)$$

b) Sand container length l_c (*m*) at the crest

$$l_c = \frac{H_s}{\left(\frac{\rho_E}{\rho_W} - 1\right) \times \left(0.79 + 0.09 \times \frac{R_c - H_s/2}{H_s}\right) \times sen\,\alpha} \qquad (2)$$

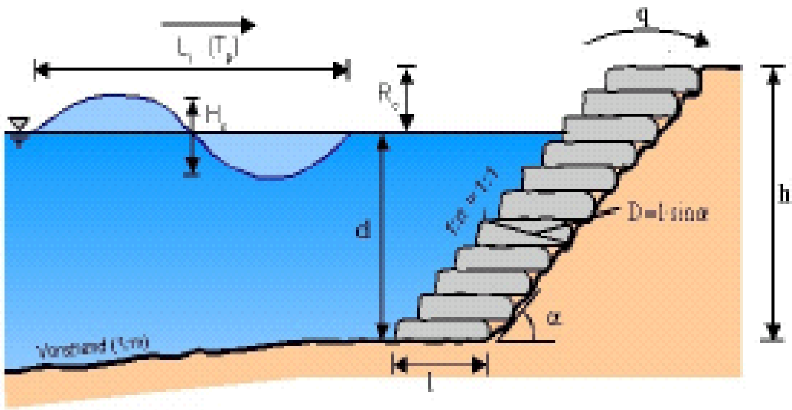

Figure 8 – Dimensioning of geotextiles reinforced dune barriers for the Leirosa sand dunes

In Leirosa case, the following calculations for geotextile sand containers at the front of the dune and at the crest have been taken as basis for the preliminary design:

- Significant wave height, H_s = 2.50 *m*
- Peak period, T_p = 16.0 *sec*
- Density sand containers, $\rho_E = (1-n)\,\rho_s + \rho_W \approx 1800\ kg/m^3$ ($\rho_s \approx 2000\,kg/m^3$; $\rho_W \approx 1000\,kg/m^3$; $n \approx 0.60$)
- Freeboard, $R_c = 0.5\,H_s + 0.50\,m$ = 1.75 *m*
- Slope angle, $\alpha = 26.6^o$

Required sand container length at the front, $l_f \approx 6.40\,m$.

Required sand container volume at the front, $V_f \approx 16.9\,m^3$.

Required sand container length at the crest, $l_s \approx 8.60\,m$.

Required sand container volume at the crest, $V_s \approx 41.9\,m^3$.

The limiting rules based on test conditions are:

1. The tests have been determined with 1:1 inclined slope (45^o);
2. Ratio $l/B = length/width$ of sand containers of 2:1 = l/B;
3. Fill volume rate of 80%.

Figure 9 – Leirosa sand dunes system, February and March 2005

REVEGETATION

On the top of the geotextiles, a 1 m layer of sand was deposited, and revegetation of the dune was performed with *Ammophila arenaria* transplants. The procedure was in all aspects similar to what have been done in 2001, except for watering.

The revegetation work occurred in an area of 3000 m^2, and it was conducted by four experience gardeners during three weeks. It started in March/April to allow the complex root and rhizome system of *A. arenaria* to better develop until the beginning of the next winter period. Although it is not very common and necessary to water the dune systems when revegetation works are performed, some irrigation was included this time due to the very dry winter of 2004/05. A container with capacity for 4000 L was used to humidify the sand before transplantation, in the beginning of every working week.

Figure 10 – Leirosa sand dunes system, from March to October 2005

MONITORING

A monitoring plan was set up and implemented immediately after the replanting work. The entire restored dune was considered, with particular attention to the replanted areas. The emergence of new species was noted and sand mobility was estimated by means of the small, graduated, wooden poles that were distributed throughout the rehabilitated system (Antunes do Carmo et al., 2006). About 8225 culms of *Ammophila arenaria* were transplanted in a tight pattern of 50 cm in a diagonal grid. Although all plants were alive at the time of transplantation, due to the stress during replanting and also because of the high temperatures, almost all plants were apparently dry after one month. However they were not dead, as could be confirmed by observing more closely the belowground system, where new roots were being formed. For this reason no parameters related to the growth or flowering of the plants were taken into consideration in the first six months of the monitoring programme.

The restored dune was delimited by a previous dune system where some other endemic plants were already growing. In only six months eleven plant species colonized an area where only *Ammophila arenaria* was planted: *Artemisia maritima*, *Calystegia soldanella*, *Crucianella maritime*, *Pancratium maritimum*, *Elymus farctus*, *Medicago marina*, *Silene littorea*, *Eryngium maritimum*, *Polygonum maritimum* and *Euphorbia paralias*. To monitor sand mobility 24 graduated wooden poles were distributed along the restored dune system in transects along the top back, top front and base of the dune. After six months some distinctions could be noticed between the three defined zones, with little or no mobility in the top of the dune and accumulations of about 4 to 6 cm of sand on the base of the dune.

LATE WINTER AND EARLY SPRING 2006

High tides of March and April 2006 have partially damaged the geotextile dune structure. The hydrodynamic forces affected the dune, leading to an opening of the geotextile layers in some parts of the three bottom layers. The opened areas allowed on an outflow of the sand fill material which further led to a partial collapse of the dune structure and settlements of the upper 5 layers. Since no failure was detected on the used geotextile, the probable cause was the inappropriate seal of the geotextiles layers, which was partially done in conditions of high humidity.

Figure 11 – Leirosa sand dunes system, March and April 2006

The next step will be the rehabilitation of the geotextile reinforced sand dune in the areas where the encapsulated sand layers have partially opened up. A proposal of rehabilitation with large geotextiles tubes, which are prefabricated to avoid failure of the joints, filled with a suspension of sand and water and placed at the bottom of the existing structure as toe protection, is being analysed.

DISCUSSION

The construction of a submarine outfall pipe temporarily damaged the continuity of the Leirosa sand dune system. The erosion that is felt in this area, aggravated by the presence of a breakwater about 1 Km north, contributed to the degradation of the dune, making an intervention required to preserve the integrity of the deaeration chamber of the outfall pipe.

Rehabilitation was first performed by reconstruction of the sand dune, followed by revegetation with the native grass species, *Ammophila arenaria*. The entire success of this work could not be confirmed, since only after 9 months, heavy storms that characterized the winter of 2000/01 destroyed the oceanic side of the rehabilitated dune. Even so, if the dune would not be reconstructed by that time, severe problems could be caused to the daeration chamber of the outfall pipe, which was protected by a stabilized dune in the back. In only a few months an extraordinary increase in the number of plant species, plant cover and sand stability, was achieved in the Leirosa sand dune system.

A few years later the protection of the oceanic side of the dune was installed. A barrier of sand containers was constructed with sand containers enclosed by geotextiles. The top layer of sand was replanted with beach grass, turning this area in an attractive and safe coastal dune system. To our knowledge, this was the first time that such procedure was used in the Portuguese coast with the advantage of working as a complement of the rehabilitation of the dune with natural vegetation. At the same time, it represents a long-term robust protection.

Although some problems have been later detected in the application of the geotextiles layers, they are now being solved. We believe that the work developed in the Leirosa sand dunes can become an important model to be applied in other dune systems with similar erosion problems.

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