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Analysis of the Dynamics of the Valdevaqueros Dune †

Lara González-Martín * and Inmaculada Concepción Rodríguez-Santalla *

Departamento de Biología, Geología, Física y Química Inorgánica. ESCET. Universidad Rey Juan Carlos. C/ Tulipán s/n 28933 Móstoles (Madrid), Spain

* Correspondence: l.gonzalezmarti@alumnos.urjc.es; inmaculada.rodriguez@urjc.es

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Abstract: The Valdevaqueros dune, located on the Atlantic coast of Cádiz (SW of Spain), is considered one of the largest transgressive dune in Europe due to its dimensions: 700 m length, 500 m width and 50 m over the sea level. It is expected that the dune will continue growing because, at the current date, any method has achieved to stabilize the dune. Valdevaqueros is located a few kilometers from the Strait of Gibraltar, where the prevalent winds of Levante cause a migration rate of 17 m/year. This fact has provoqued the burial of the regional road, so maintenance task must be done periodically. In view of this troublesome, the Valdevaqueros dune has been the subject of numerous studies with the purpose to obtain a correct characterization of its behavior and evolution. Throw out this work, the dune will be studied between 2008 and 2015 by means of three analysis kind: the spatial and volumetric variation of the dune field using LiDAR data, the shoreline evolution supported by the ArcGIS DSAS extension; and the study of its internal structure using GPR data. The results reveal that the dune has doubled its size and volume, the sedimentary patterns on the windward face of the dune are associated with foreslope and the coastal environment is mostly erosive. This study represents a significant advance in knowledge of this dune dynamic.

Keywords: Valdevaqueros dune; LiDAR data; coastal migration; Ground-penetrating radar (GPR)

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1. Introduction

According to the latest IPCC report [1], sea level is expected to continue to rise over the century, even under a scenario of very low GHG emissions, it is estimated that sea level could rise between 0,28 and 0,55 m, progressively rising to 1,88 m in worst-case scenarios, reaching 2 m in 2100. This rise poses a risk to coastal population: [2] have obtained through a procedure with LiDAR, that 35 million people are living in areas below 0 m, being at extreme risk from floods, and 267 million are in countries below 2 m, suffering a potential risk. It is also estimated that the human population living on the coast will increase to 286 million by 2030 and will exceed 300 million by 2060 [3].

Coastal dune systems are transitional systems between the marine and continental environments. In general, they can be characterized as systems with great physical dynamism, which in turn makes them extremely vulnerable to human alterations [4]. This dynamism is due to its environmental function, as the dunes act as a barrier to external destructive forces such as marine storms. The sandy formations absorb this impact [5], slowing both the waves and the wind, thus avoiding the invasion of the sea towards the interior of the coast. This fact is of great importance as it provides protection against the foreseeable rise of the sea. Therefore, it would be interesting to study the dune systems throughout the world to be able to establish an environmental planning against possible floods.

2. Study Area

The Valdevaqueros dune, located 10 km to the NW from Tarifa (Cádiz, Spain) (Figure 1), is considered largest transgressive dunes in Europe: 700 m length, 500 width and 50 m over the sea level [6]. The strong winds of Levante that predominate in the area generate a migration rate of 17 m/year, causing the burial of the road A-2325 [7], located at the foot of the dune, by its leeward face.

Figure 1. Topographic map of the Strait of Gibraltar, with the marked location of the Cove of Valdevaqueros (Instituto Geográfico Nacional (IGN) [8]). Including an aerial image of the dune in 2020 [8].

Among the various aspects that have caused this phenomenon, the main one is the human intervention in the system: [9] show that the alteration of the sedimentary regime dates back to 1939, when approximately 500 forts were built along the coast of the Strait of Gibraltar at the outbreak of the Second World War, causing the imbalance between the Cove of Valdevaqueros, Los Lances and Tarifa.

One of the solution that was being developed to try to stop the dune was sand extraction, however, in 1998 the Coastal Law was published, which, among others observations, prohibited the extraction of sand in order to protect the Spanish coast. After that [10] contemplate that Valdevaqueros dune has experienced a greater growth compared to previous year.

At current date, no method has been found which to stabilize the dune, because the strong winds of the area and the great sedimentary load transported exceed the retaining capacity of the vegetation or artificial barriers [11].

3. Materials and Methods

3.1. Morphological Variation Analysis

First, a quantitative and qualitative analysis of how the volume and area of the dune have varied is carried out. To this end, we are working with the first LiDAR (Light Detection And Ranging) coverage for 2015 and the DEM (Digital Elevation Model) for 2008, obtained from the IGN [8]. From both years, the dune field is extracted by manual digitization with the support of aerial photographs, in order to compare them.

The treatment and data comparison were realized using ArcGIS 10.8: using Cut and Fill tool, that shows the zones of loss and gain in height, and Surface Volume tool, that calculates the area and the volume for each year.

Additionally, three topographic profiles have been studied along the dune observing how the dune has been changing and determining more dynamic areas than others.

3.2. Coastal Evolution Analysis

The Digital Shoreline Analysis System [12] gets the accretion and erosion zones of the beach by a series of transects projected from a baseline that cut the target lines, in this case, the 2008 and 2016 shoreline obtained from aerial photographs.

DSAS provide three statistics [12]:

- NSM (Net Shoreline Movement): shows the distance between the oldest and most current line per transect.
- SCE (Shoreline Change Envelope): shows the distance between the furthest and closest line to the baseline for each transect.
- EPR (End Point Rate): calculates the annual rate of coastal migration. Is the value of NSM divided by the time interval in years between those lines, expressed as the change in m/year.

3.2. Analysis of the Internal Structure

The study of the internal structure consists of the sequence of three Ground Penetration Radar (GPR) profiles of the windward face. Similar to a stratigraphic study, in each of the profiles different sedimentary patterns are identified with which the evolution of the dune can be reconstructed.

4. Results

4.1. Volumetric Variation

The Table 1 shows the rates of change of area and volume in the different periods.

Table 1. Data of surface, volume and maximum height of the dune field for the year 2008 and 2015, in addition the calculation of the percentage of growth is incorporated.

	Study year	Area (m^2)	Volume (m^3)	Maximum height (m)
	2008	167.900	2.848.295,94	45,70
	2015	235.000	4.320.088,50	49,59
Net change	-	67.100	1.471.792,56	3,89
Change (%)	-	**39,96**	**51,67**	**8,5**

It can be observed that, in the course of 7 years, the surface of the dune field has increased by almost 40%, reaching 23,5 ha, while the volume has grown by more than 50%. The height obtained from the DEM has barely increased by 8%.

The migration of the dune determinate by the map Cut and Fill tolls (Figure 2. Left), shows the central zone corresponding to the dune in 2008, which over time has been displaced by de easterly winds towards the NW (red zones), where an increases of the sediment volume is observed. The A-2325 road can also be seen.

In order to complete the migratory analysis, topographic profiles have been plotted (Figure 2. Right): to establish a reference a point, in this case the road that would be located at point 6; from there can be observed as the ridge of the dune has been shifted towards the NW, seeing as the road has been reached and buried.

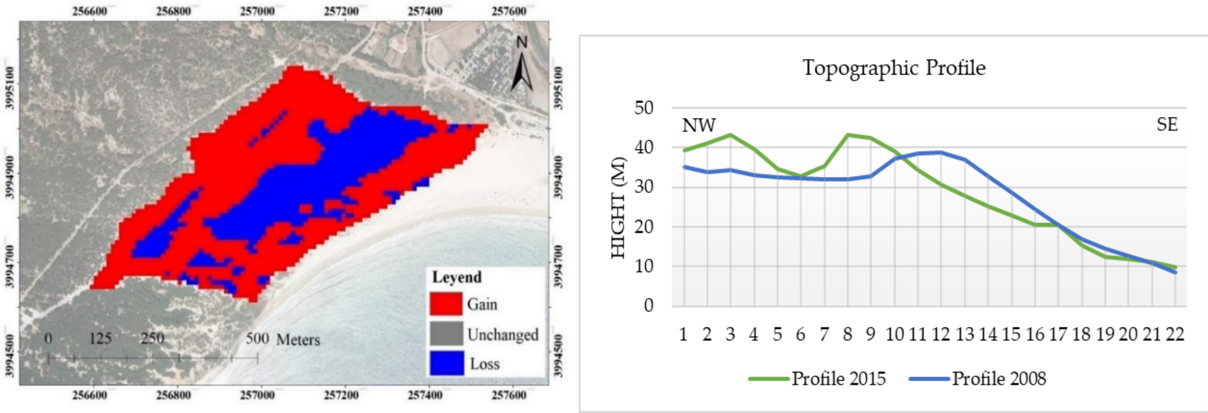

Figure 2. Left: Volumetric variation representation of the Valdevaqueros dune, showing loss and gain zones (blue and red) between 2008 and 2015. **Right**: Topographic Profile of the Valdevaqueros dune for 2008 and 2015.

4.2. Shoreline Evolution

The NSM and EPR values obtained shows that of the 37 transects, 29 of them are in erosion situation with an average loss of 10.4 m with a maximum of 18.5 m; on the other hand, the remaining 8 transects are in accretion with an average growth of 9.56 m with a maximum of 11.8 m. The value of the EPR for the entire data set is -0.86 m/year, establishing that the beach of Valdevaqueros is in erosion.

4.3. Sedimentary Dynamics

Due to its great length, those radargrams of greatest interest will be analyzed. The first of these, the steepest zone of the profile (Figure 3): at 80 m it can see how the reflectors being to step uphill in the NW direction, associated with different wind impulses, causing hyperbolic truncations and outcrops, as a result of the slope, wind intensity and the presence of vegetation. Relative to the other interest area (Figure 4): in the central area, a blowout sedimentary structure can be identified, a dune depression that, according to [13], is associated with the incidence of strong winds, which push the sand to the outside of the depression, being observed in the reflector themselves that present truncations in opposite directions to each side of the depression.

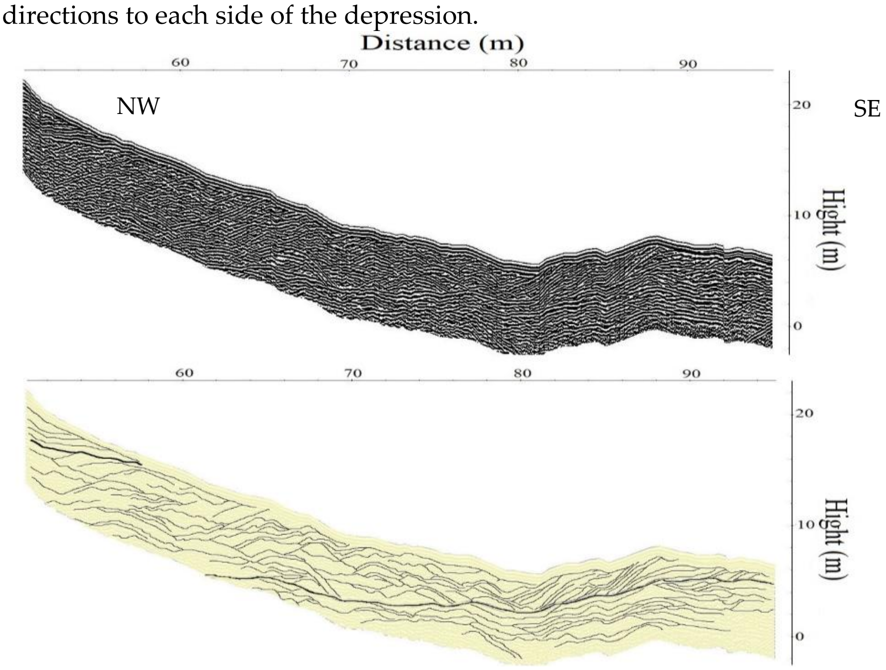

Figure 3. Part of the radargram corresponding to the beach-crest transect and its corresponding interpretation.

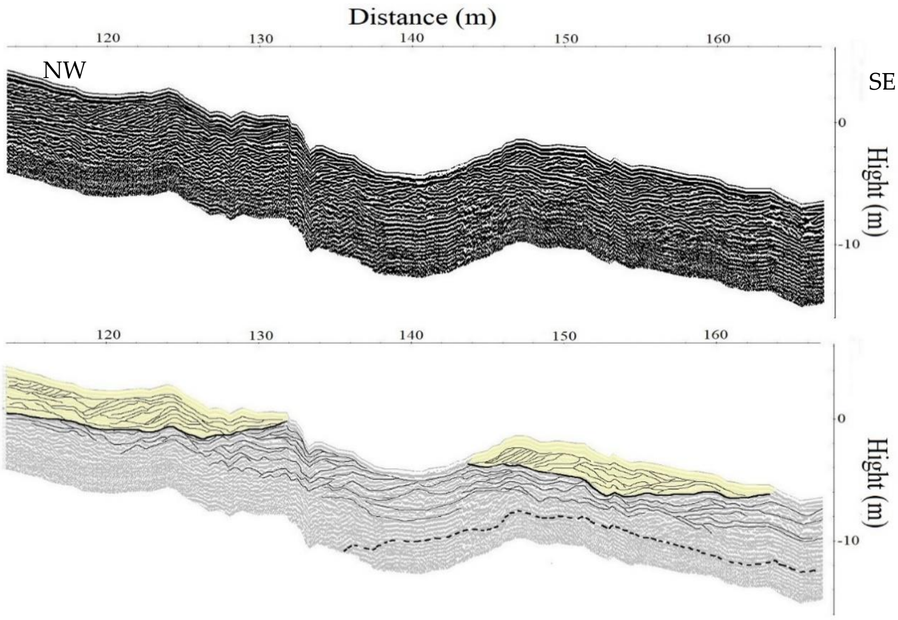

Figure 4. Part of the radargram corresponding to the beach-crest transect and its corresponding interpretation.

5. Discussion and Conclusion

The study ofsurface and volume variation of the dune fields has varied at is of great importance to address the correct environmental management of the dunes. Use LiDAR technology to obtain DEMs facilitates this process by its ability to process a large sample of data, allow various calculations on them and give clear and simple results, making a rigorous and correct diagnosis of the dune's behavior. With the GPR technology, the internal structure of the dune is obtained in a simple and fast way, being able to examine the different sedimentary trends throughout the profile, to obtain the evolution that the dune has had.

With respect to its morphological variation of the Valdevaqueros dune, the surface has been increase about 40% and its volume more than 50% in 7 years. A growth rate of 300 m^3/m/year has been obtained, and taking into account the results of other authors [14,15] it can be established that the dune increases its volume by 289 m^3/m/year on average.

The evolutionary trend of the coastline is erosive, but a more real analysis would be obtained with a technical study that analyzes the evolution of coast in a much wider period along with winds and tides, in order to have a much more representative trends.

Finally, the internal structure of the dune develops with a certain variety of sedimentary structures that differ along the profile due to the different intensities and directions of the wind. As a rampant dune, the slope plays an important role in sedimentary formations [16–18]. Truncations and hyperbolic reflectors are observed on both sides of the dune: in windward they are associated with winds of different directions [19], where it has also been possible to describe blowout formations, which consist of depressions caused by the retention of sediment by vegetation, which slows the wind causing it to push the sand out, coinciding with one of the descriptions proposed by [13]; and in the leeward face, these relationships of the reflectors are associated to the processes of sliding and falling down the slope, as well as, to the barefoot in the lower parts of the dune by the cleaning operations of the road [17]. The study of sedimentary dynamics has been a novel advance for the complete knowledge of the Valdevaqueros dune, since until now, it had not been addressed in the area.

References

1. IPCC: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press. **2021.**
2. Hooijer, A & Vernimmen, R. Global LiDAR lan elevation data reveal greatest sea-level rise vulnerability in the tropics. *Nat. Commun* **2021**, *12*, 3592.
3. McMichale, C; Dasgupta, S; Ayeb-Karlsson, S & Kelman, I. A review of estimating population expusure to sea-level rise and the relevance for migration. *Environ. Res. Lett.* **2020**, *15*, 123005.
4. Ley, C; Gallego, J.B &Vidal, C. Manual de restauración de dunas costeras. Ministerio de Medio Ambiente, Dirección General de Costas, España, **2007**, 250 pp.
5. Quintana, X & Vicens, J. Presentacion. En Riog-Munar, F,X. (eds). *Restauración y gestión de sistemas dunares. Estudio de caos*. Càtedra d'ecosistemens litorals mediterranis, **2016**, pp. 9-10.
6. Navarro, M; Muñoz-Pérez, J.J; Román-Sierra, J; Ruiz-Cañavante, A & Gómez-Pina, G. Characterization of wind-blow sediment transport with height in a highly mobile dune (SW Spain). *Geologica Acta* **2015,** 13(2), 155-166.
7. Muñoz-Pérez, J.J; Navarro, M; Román-Sierra, J; Tejedor, B; Rodríguez, I & Gómez-Pina, G. Long-term evolution of a transgressive migration dune using reconstruction of the EOF method. *Geomorphology* **2009**, *112*, 167–177.
8. Instituto Geográfico Nacional. Available online: Instituto Geográfico Nacional (ign.es) (accesed on 18 April 2021).
9. Bello-Millán, F.J; Somoano, M; Clavero. M; Gómez-Pina, G & Losada, M.A. El sistema dunar de Valdevaqueros: Evolución histórica y alternativas de gestión. *Ribagua* **2016**, *3*, 46–55.
10. Fagés. L; Gómez-Pina, G; Navarro, M; Román-Sierra, J; Giménez-Cuenca, M; Ruiz, J.A & Muñoz-Pérez, J.J. Coastal management activities in Valdevaqueros Dune Area (Tarifa, SW Spain). *International Conference on Management and Restoration of Coastal Dunes* (ICCD 2007) **2014**, 168-171.
11. Gómez-Pina, G; Muñoz-Pérez, J.J; Ramírez, J.L & Ley, C. Sand dune management problems and techniques, Spain. *Journal of Coastal Research*, **2002**, *36*, 325–332.
12. Himmelstoss, E.A; Henderson, R.A, Kratzmann, M.G & Farris, A.S. Digital Shoreline Analysis System (DSAS) Version 5.0 User Guide. U.S. Department of the Interior and U.S. Geological Survey, **2018**, 126 pp.
13. González-Villanueva, R; Costas, S; Duarte, H; Pérez-Arlueca, M & Alejo, I. Blowout evolution in a coastal dune using GPR, aerial imagery and core records. *Journal of Coastal Research, Special Issue 64*: Proceedings of the 11th International Coastal Symposium, **2011**, 278-282.
14. Navarro, M. Modelización de la evolución morfodinámica de la duna de Valdevaqueros (T.M. Tarifa) mediante la aplicación de funciones empíricas ortogonales a corto, medio y largo plazo. Tesis Doctoral. Universidad de Cádiz, España, **2011**.
15. Navarro-Pons, M; Muñoz-Pérez, J.J; Román-Sierra, J & García, S. Evidence of coastal dune mobility increases over the last half century in response to historical human intervention. *Scientia Marina*, **2016**, 80(2), 261-272.
16. Rodríguez, I; Sánchez, M.J; Montoya, I; Gómez, D; Martín, T & Serra, J. Internal structure of the aeolian sand dunes of El Fangar spit, Ebro Delta (Tarragona, Spain). *Geomorphology*, **2008**, *104*, 238–252.
17. Flor-Blanco, G; Rubio, D; Flor, G & Fernández, J.P. Estructura interna e interpretación de la evolución del campo dunar eólico de Xagó (costa central de Asturias, NO de España). *Conference 7º Simpósio sobre a Margem Ibérica Atlântica, Lisboa*, **2012**, 71-76.
18. Fernández, G.B; Figueiredo, M.S; Rocha, T.B; Maluf, V.B; Martins, C & Moulton, M.B.A. Foredunes Morphological Changes by Offshore Winds Revealed By Grund-Penetrating Radar: Massambaba Beach – Rio de Janeiro, Brazil. *Journal of Coastal Research,* **2016**, *75*, 278–282.
19. Rodríguez-Santalla, I; Gómez-Ortiz, D; Martín-Crespo, T; Sánchez, M.J; Montoya-Montes, I; Martín-Velázquez, S; Barrio, F; Serra, J; Ramírez-Cuesta, J.M. & Gracia, F.J. Study and Evolution of the Dune Field of La Banva Spit in Ebro Delta (Spain) Using LiDAR Data and GPR. *Remote Sensing*, **2021**, *13*, 17 pp.