EVALUATING THE IMPACT OF SAND FENCES ON FOREDUNE RECOVERY IN SANT PERE PESCADOR BEACH (COSTA BRAVA, SPAIN)

Carla Garcia-Lozano, Warren Meredith, Maria Marta Tonda, Josep Pintó, Carolina Martí-Llambrich, Ventura Campillo, Francesc Xavier Roig-Munar

Abstract: Coastal dune systems have been significantly altered due to erosion from environmental and human factors, and nature-based solutions have become important in restoring these ecosystems in the face of climate change. The *el Cortal de la Devesa* beach (Gulf of Roses, NE Spain) has been the focus of such nature-based solutions with the installation of sand fences. Two campsites along this beach have implemented contrasting integration strategies over time. The Northern campsite has defined its boundaries and regulated beach access, while the Southern campsite did not. This study aimed to develop high-resolution (10 cm) digital elevation models to quantify changes in sediment retention and dune height both pre and post construction of the fences, to assess differences between the campsites. Results indicated the Northern site had higher overall values in average height, maximum height and volume of sand dunes than in the Southern site. Also, a porosity of 50-60 % proved 85 % efficient in this context. This study contributes objective data that highlights the potential role that tourist-recreational sites play along coastlines in climate change resilience.

Keywords: dune restoration, nature-based solutions, sand fences, rope fences, Catalan coast.

Carla Garcia-Lozano, University of Girona, Spain, carla.garcia@udg.edu, 0000-0002-5071-1009
Warren Meredith, University of Girona, Spain, warren.meredith@udg.edu, 0000-0002-2927-326X
Maria Marta Tonda, University of Girona, Spain, maria.marta.tonda@gmail.com, 0000-0001-9233-4005
Josep Pintó, University of Girona, Spain, josep.pinto@udg.edu, 0000-0002-5693-393X
Carolina Martí-Llambrich, University of Girona, Spain, carolina.marti@udg.edu, 0000-0003-4189-5878
Ventura Campillo, University of Girona, Spain, ventura.campillo@udg.edu
Francesc Xavier Roig-Munar, University of Girona, Spain, xiscoroig@gmail.com, 0000-0002-9777-0938

Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Carla Garcia-Lozano, Warren Meredith, Maria Marta Tonda, Josep Pintó, Carolina Martí-Llambrich, Ventura Campillo, FrancescXavier Roig-Munar, *Evaluating the impact of sand fences on foredune recovery in Sant Pere Pescador beach (Costa Brava, Spain)*, pp. 730-740, © 2024 Author(s), CC BY-NC-SA 4.0, DOI: 10.36253/979-12-215-0556-6.63

Introduction

Coastal dunes are dynamic structures formed by wind-transported sediments accumulating against natural obstacles, primarily plant debris deposited by wave action on elevated beaches. These obstacles reduce wind transport and encourage vegetation growth, leading to the formation of initial dunes that eventually develop into more substantial foredunes. The primary source of these sediments is the beach, where tidal variations and wave dynamics deposit sand, as detailed by [1] and [2]. Dunes are continuously shaped by environmental factors such as wind, water, and human activities. Their formation and characteristics are influenced by local climate conditions, wind patterns, sand availability, and vegetation presence. The global distribution of dunes showcases significant variance in size, from modest hills to expansive areas stretching thousands of kilometers. This diversity is classified based on material characteristics and formation processes, with types including transverse, longitudinal, oblique, linear, and star dunes [3]. Coastal dunes, often smaller than their desert counterparts, are crucial for protecting shorelines from sea level changes and storm impacts, necessitating thorough research and science-based management strategies. As dunes grow, they support more varied plant species, indicating increased dune stabilization. This ecological succession, along with factors such as sand mobility and erosion tolerance, plays a pivotal role in shaping dune landscapes, as described by [4] and [2].

Currently, global dune degradation, driven by tourism and urbanization, underscores the urgency of conservation. In Europe, dune areas have declined by approximately 70 % in the past century, with Catalonia losing nearly 90 % of its dunes [5]. Increased conservation efforts have emerged, exemplified by Spain's legislative measures and the establishment of protected areas. The "European Dune Conference" in 1987 and the formation of the "European Union for Coastal Conservation" highlighted the commitment to dune preservation. One of the recognized methods involves strategic use of sand fences to retain sediment and disrupt wind-driven transport. These structures, ranging from synthetic plastic meshes to natural fabric meshes, are crucial for mitigating wind effects on sediment movement. Their design, particularly porosity and alignment with prevailing winds, is critical for effectiveness, with a general recommendation of 40÷50 % porosity [14].

El Cortal de la Devesa beach (Gulf of Roses, NE Spain) is a 2-kilometer-long beach-dune system that has faced significant tourism pressure and has been the focus of such nature-based solutions. Under a dune restoration project, the installation of sand fences and rope fences was completed in 2020, along with various management strategies to stop mechanical cleaning of the upper beach. This part of the coastline is also entirely encompassed by developed campsites. Within this area, two campsites have adopted contrasting management approaches over time. The Northern campsite has clearly defined its boundaries and regulated beach access. In contrast, the Southern campsite, where management ceased in 2021, has neglected to control beach access, limit mechanical cleaning, and has also been overrun by invasive plant succession. Using unmanned aerial vehicles (UAVs), the objective of this study was to create high-resolution (10 cm) digital

elevation models for quantifying changes in sediment retention and dune height before (2019) and after (2023) the construction of the fences. This was done to evaluate variances between the Northern and Southern campsites. By comparing these distinctly managed areas, the aim is to gain a more comprehensive understanding of coastal dune dynamics and to contribute to the development of more effective strategies for their preservation and restoration. A key focus is the challenge of foredune recovery, emphasizing the critical role of management practices in camping areas and visitor behavior. This study also provides empirical evidence, underscoring the significant potential of tourist-recreational sites in bolstering climate change resilience along coastlines. Implementing management strategies with nature-based solutions could improve beach-dune profiles, thus safeguarding coastal users and facilities from the impacts of climate change.

Study Area

The Gulf of Roses is located on the Alt Empordà plain, on the Northern coast of Costa Brava (Catalonia, Spain). El Cortal de la Devesa beach is located in the Southern section of the gulf (Figure 1), where sediment transported by the longitudinal current from the NNE contributes to the formation of the widest beach, spanning between 50 and 75 m in width. Stretching 2 km in length, *el Cortal de la Devesa* beach encompasses a total area of 15 hectares.

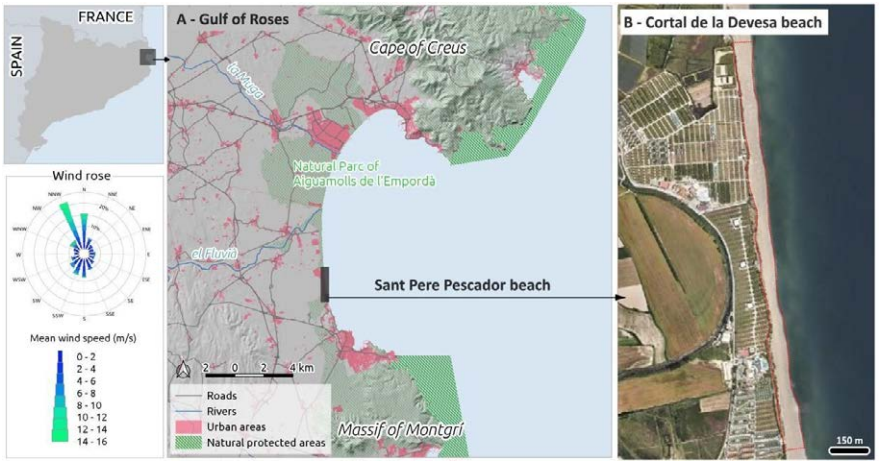

Figure 1 – Study Area: *el Cortal de la Devesa* beach (B) is in the Southern sector of the Gulf of Roses (A), Spain. The precise area under study is indicated with red dots. The 2023 aerial photograph. Source: Cartographic and Geological Institute of Catalonia (ICGC), and Spanish Institute of Oceanography (IEO).

The beach-dune systems in the Gulf of Roses feature transversal dunes, some with parabolic and barchanoid shapes, and foredunes on the upper beach. South of the Fluvià river mouth, the coastline's orientation shifts, enabling *the tramontana* winds from the north to create one of Spain's most significant mobile dune systems [5]. These dunes, devoid of vegetation and crescent-shaped with horns pointing leeward, form under strong winds in sediment-rich areas. The prevailing north-northwest winds push these dunes parallel to the coast, primarily consisting of well-sorted medium and fine sands. The foredunes here are weak and fragmented, marking the transition between the beach and wetlands. The southern Gulf of Roses, facing north, receives sediment from the north via longshore currents, forming smaller barchans. These dunes undergo cycles of destruction and formation multiple times a year due to storm conditions and wind patterns. The inner arms of the barchans play a crucial role in supplying sediment to the foredunes, which are then stabilized by vegetation, delineating the sandy coastal areas from the marshlands.

Materials and Methods

This study investigated the geomorphological changes of the foredune between 2019 and 2023 following the implementation of recovery-oriented management measures (Table 1A). The sand traps constructed in 2020 have dimensions of 10÷15 m in length, with a 50÷60 % porosity and a height of 85 cm, a width between 10 and 15 m each, and orientated NNW (Figure 2).

Figure 2 – Sand fences at the Northern campsite almost completely buried by sand, showcasing the natural accumulation process over time.

Unmanned aerial vehicles (UAVs) with RGB sensors were used to collect data before and after the installation of sand fences. High-resolution (10 cm) digital elevation models (DEM) were generated from the collected data using PIX4Dmatic software which is based on photogrammetric techniques. For high-resolution DEMs, 80 % frontal and 70 % lateral image overlap were used, with a flight altitude of 70 m. Both ground control points and checkpoints were utilized to

calibrate the DTMs and assess their accuracy. The checkpoints specifically measured the error in the Z-axis of the DTMs, with the Root Mean Square Error (RMSE) calculated using the Point Sampling Tool plugin in QGIS. This allows us to confirm that we are working with digital topographic models with an average altitude error of 4 cm.

UAV flights occurred in May 2019 and in May 2023, before and after the implementation of management measures. Analyses focused on sediment accumulation, including variations in dune height (Average height (AH), maximum height (maxH), and minimum height (minH)) and volume development (Vol) (Table 1). These variables were calculated from the delimited foredune within each grid block using native tools in QGIS 3.34.1 and ArcGIS Pro.

The criterion for defining the studied foredune area varied according to the beach section and the management measures implemented. Although it always starts from the appearance of the foredune notch in 2019, the end of the foredune was delineated based on following criteria. When sand and rope fences were installed, the foredune was considered from the foredune notch presented in 2019 to the restricted area marked by rope fences installed in 2020; when no rope fences were implemented, the foredune area was considered between 25 m from the foredune notch presented in 2019.

The Northern campsite extends 800 m along the beach profile, while the Southern campsite extends 1200 m, resulting in comparative analyses of values between the two campsites of 8 grid blocks and 12 grid blocks (100 m length), respectively.

Statistical analyses included the independent samples t-test to determine significant differences between the means of the Northern and Southern campsites. The test was conducted under the hypothesis that the Northern campsites' sand accumulation and height was greater than the Southern campsite, expressed as $H_a\ \mu N > \mu S$, with a confidence level of 95 %. Analyses were conducted using the jamovi project (2021) (jamovi Version 2.2.2, Computer Software, retrieved from https://www.jamovi.org).

Results

The delineation of the grid blocks (100 m in length) and foredune shape area for sand accumulation calculations are shown in Figure 3. The blocks from 1 to 8 are situated adjacent to the Northern campsite, whereas blocks 9 to 20 are located opposite the Southern campsite. Therefore, these blocks have been respectively linked to the Northern and Southern campsites for assessing the results of this analysis. There is a clear relationship between management measures applied in the Northern section of el *Cortal de la Devesa* beach and sand accumulation on the foredune. Sand fences and rope fences have led to an increase in both average height and volume, predominantly ranging from 1 m to 1.5 m in height and reaching maximum values exceeding 2 m (blocks 1 to 7 in Figure 3). The volume of sand ranges from 25 to 40 m^3 per 25 m^2.

Conversely, volumetric and altimetric increases in the Southern beach zone have not been as notable due to the absence of management measures of nature-based solutions such as sand fences and rope fences. Nevertheless, it is noteworthy that mechanical leveling and cleaning operations have ceased in the Southern sector, potentially contributing directly to dune system improvement. This factor may have resulted in height increases ranging from 40 to 60 cm in some blocks, whereas in others such as blocks 9, 15, and 16, the average height does not exceed 40 cm. The blocks with less sand increase are characterized by numerous pathways and access points from the campsite to the beach, may have influenced dune recovery.

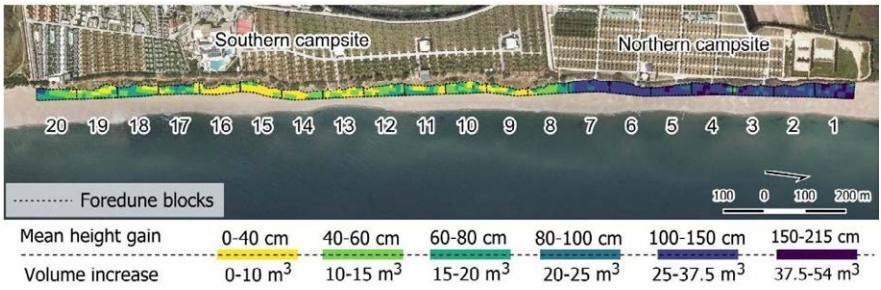

Figure 3 – Topographic changes at *el Cortal de la Devesa* beach from 2019 to 2023, detailed by the mean height gain and volume increase in the foredune, using a 5 square meter grid per cell.

Table 1 indicates averages of the development of sand dunes between the two campsites both in the years of 2019 and 2023. The Northern campsites dune profiles indicate lower average height, minimum height and volumes compared with the Southern campsite in 2019. However, in 2023, average height, maximum height and volumes increased by 60.1 %, 41 % and 60.15 %, respectively, surpassing the Southern campsite in overall values. The Southern campsite values showed modest increases in average height, maximum height and volumes, with 23.4 %, 20.4 % and 23.8 % respectively. In 2023, the Northern campsite's total volume accounted for 65.6 % of the total beach volume from sea level of the study area, while the Southern campsite's total volume made up the remaining 34.4 %.

Prior to the implementation of the sand fences in 2019, no significant differences were found between the Northern and Southern campsites in dune average height, maximum height, minimum height, and volume (Table 2). However, the Northern campsite dunes increased significantly in 2023 and were greater than the Southern campsite's dunes in all variables except for minimum height, which did not vary significantly between the Northern and Southern campsites.

Table 1 – Averages of sand accumulation between the Northern campsite (N) and the Southern campsite (S) for each grid block (Block) for average sand dune height (AH), maximum dune height (maxH), minimum height (minH) and sand dune volume (Vol) within each grid block between years 2019 and 2023. The difference in accumulation is calculated by subtracting values in 2023 by values in 2019.

		2019				2023				Difference 2019-2023			
GridBlock	Campsite	AH	maxH	minH	Vol	AH	maxH	minH	Vol	AH	maxH	minH	Vol
1	N	0.83	2.25	-0.03	2596.68	2.18	3.78	1.41	6821.64	1.35	1.53	1.44	4224.96
2	N	1.02	2.39	0.25	2762.27	2.16	3.73	1.44	5877.84	1.14	1.34	1.20	3115.57
3	N	0.81	1.94	0.31	1812.80	2.00	3.68	1.11	4523.51	1.20	1.74	0.81	2710.71
4	N	0.82	2.80	0.22	2177.11	2.11	4.09	1.13	5632.14	1.29	1.29	0.91	3455.03
5	N	0.73	1.56	0.24	1714.31	2.04	3.47	1.34	4808.27	1.31	1.91	1.11	3093.96
6	N	0.75	2.17	0.23	1892.12	2.05	3.62	1.27	5169.62	1.30	1.45	1.04	3277.49
7	N	0.87	1.83	0.25	2380.00	2.02	3.17	1.43	5574.01	1.16	1.34	1.17	3194.02
8	N	1.72	3.35	0.85	3451.91	2.31	3.88	1.43	4645.11	0.59	0.53	0.58	1193.19
9	S	1.61	3.11	1.08	3000.95	1.95	3.25	1.31	3647.07	0.34	0.14	0.24	646.12
10	S	1.56	2.58	0.91	3920.41	2.07	3.41	1.44	5217.22	0.51	0.83	0.53	1296.81
11	S	1.37	2.69	0.65	3090.08	1.90	3.21	1.11	4297.83	0.53	0.51	0.46	1207.75
12	S	1.47	2.63	0.77	3618.59	1.98	3.25	0.55	4878.07	0.51	0.62	-0.22	1259.49
13	S	1.54	2.76	0.93	3215.27	1.94	3.37	1.16	4059.13	0.40	0.61	0.23	843.86
14	S	1.49	2.47	0.91	2817.92	1.84	2.91	1.30	3490.38	0.35	0.44	0.39	672.46
15	S	1.63	2.58	1.00	3916.71	1.95	3.11	1.42	4706.87	0.32	0.54	0.42	790.16
16	S	1.68	2.91	1.14	3383.37	1.96	3.17	1.34	3959.68	0.28	0.26	0.19	576.31
17	S	1.50	2.45	0.95	3361.97	2.05	3.46	1.50	4607.35	0.55	1.01	0.55	1245.38
18	S	1.51	2.75	0.95	3726.57	2.08	3.35	1.63	5147.27	0.57	0.60	0.68	1420.70
19	S	1.52	2.09	0.99	3886.71	1.97	3.08	1.13	5046.28	0.45	0.99	0.14	1159.57
20	S	1.25	1.67	0.82	3061.27	1.89	3.35	1.55	4660.28	0.65	1.67	0.74	1599.01
TOTAL	N	0.9	2.3	0.3	2348.4	2.1	3.7	1.3	5381.5	1.2	1.4	1.0	24264.94
TOTAL	S	1.5	2.6	0.9	3416.7	2.0	3.2	1.3	4476.5	0.5	0.7	0.4	12717.61

Table 2 – Independent samples t-test to determine significant difference between the means of the Northern and Southern campsites for average height (AH), maximum height (maxH), minimum height (minH) and volume (Vol). The test was conducted under the hypothesis that the Northern campsites' sand accumulation and height was greater than the Southern campsite, expressed as: $H_a\ \mu N > \mu S$ with significance of $p < 0.05$ indicated with asterisks.

2019				**2023**			
Variable	**Statistic**	**df**	**p**	**Variable**	**Statistic**	**df**	**p**
AH	-12.84	18	1	AH	1.84	18	0.04*
maxH	-2.48	18	0.98	maxH	3.01	18	0.004*
minH	-12.32	18	1	minH	0.05	18	0.48
Vol	-6.82	18	1	Vol	3.36	18	0.002*

Discussion

Before the implementation of nature-based solutions and the installation of the sand fences, both the Northern and Southern campsite beaches had similar sand dune morphologies, with the Southern campsites' average height and minimum height significantly higher than the Northern campsites' (data not shown here). Although the reasons for this fall outside the scope of this study, the installation of the fences in 2020 appeared to have an influence in the increase in sand accumulation in both areas, which is evident in the increases in the Southern campsite by 2023. However, with the management of dune restoration ceasing in the Southern campsite's beach area in 2021, the accumulation slowed, with the Northern campsite´s sand accumulation surpassing the Southern campsite by 2023, accounting for over 60 % of the total sand volume for the entire study reach. Previous studies found that the main causes of dune degradation in Spain included, amongst others, massive tourist development and that once mitigated or controlled, "soft" techniques such as sand trapping and dune fencing were effective in reducing dune degradation [6]. The significant changes experienced over a short time span between the two campsite areas indicate the effectiveness of these implementations and highlight the importance of managing these areas after installation. Without regulating beach access and limiting mechanical cleaning, the effectiveness is somewhat negated, with slower progression in dune recovery and more susceptibility to other occurrences, such as invasive plant succession [7] and [8]. Given the destructive-formative cycles that occur annually, vegetation stabilization is crucial in reinforcing the first stage of dune succession created by sand trapping and is linked to access control and fencing. The rate of sand accumulation over a 4-year period also indicates the potential for recovery, given the right conditions.

Furthermore, the use of UAVs in this study has provided empirical data for comparison between two distinctly managed areas and has provided insights into

coastal dune dynamics under strategies that are often difficult to quantify, given the qualitative nature associated with the implementation and enforcement of such strategies. Highly accurate coastal monitoring is challenging at best, given the complexity of coastal landforms [9]. Only by accurately mapping the changes over time of sand dune dynamics and growth can assessments of management be accurate and objective. In the same study area, [10] examined the historical evolution of beach-dune systems over the past five decades and identified a clear relationship between sustainable management measures or nature-based solutions and the recovery of the dune system over time. However, they did not employ empirical methods capable of quantifying dune recovery, relying instead on a more qualitative approach compared to the quantitative methods utilized in this study.

Interestingly, comparable results were observed at the *La Pletera* beach, located in Costa Brava, NE Spain [11]. Notably, the primary height of the foredune increased from 1.6 m to 2.7 m between 2017 and 2018 following the installation of sand fences. This mirrors the elevation change observed at the northern part of *El Cortal de la Devesa* beach (Table 1), which showed an increase from 0.9 m to 2.1 m, marking the most significant findings in our study. The average increase at La Pletera beach was comparatively higher (68 %) than the increase observed at the northern part of *El Cortal de la Devesa* beach (60.1 %). This difference can be attributed to La Pletera beach's initially lower elevation above sea level and the limited one-year duration of the current study. This study at la Pletera suggests that the implementation of management measures is unequivocally the key factor in dune recovery regarding morphology. In fact, the unmanaged areas of our study, such as the Southern campsite, have not achieved comparable figures to those attained at la Pletera beach or the northern sector of *el Cortal de la Devesa* beach, failing to even reach a 25% increase in average height, rising from 1.5 m to 2 m in average elevation.

Most field and wind tunnel studies suggest that sand-trapping fences with porosities around 40 % to 50 % are most effective in capturing sand drift [12]. Fences that are too dense can alter wind direction, whereas overly porous ones have a limited impact on airflow, resulting in minimal sand deposition. In contrast to established recommendations, studies along the Costa Brava employed fences with porosities ranging from 50 % to 60 %, yielding positive outcomes. Similarly, research conducted in Taiwan [13] achieved favorable results with a porosity of 66%, challenging prevailing guidelines found in reviews and manuals. Given the unique dynamics and complexities of each beach environment, it is prudent to conduct rigorous tests and trials specific to the site before installing sand fences. This assessment should include a thorough examination of factors such as porosity, height, and fence density to optimize the effectiveness of the restoration strategy.

Conclusion

As tourism-driven dune degradation increases, so too does the need for integrated conservation strategies by combining nature-based solutions with management strategies, to restore and protect these important ecosystems. The use

of UAVs in this study has quantified changes in sediment retention and dune height of the foredune area of both campsite areas between 2019 and 2023 and has provided a unique comparison of inherently similar morphologies and climatic conditions, but with different management strategies. Despite the initial increase in sand accumulation in the foredunes of both areas, the Northern campsite surpassed the Southern campsite by 2023 in volume, maximum height, and average height. This is attributed to the discontinued management of people access and mechanical cleaning of the foredune area in 2021 in the Southern campsite. Also, an 85 % efficacy in trapping sand was noted with a sand fence porosity of 50÷60 %. Through empirical evidence, this study has highlighted the potential of tourist-recreational sites in bolstering climate change resilience along coastlines. Implementing management strategies with nature-based solutions could improve beach-dune profiles, thus safeguarding coastal users and facilities from the impacts of climate change.

Acknowledgements

This research has been carried out within the framework of the IMPETUS project (ref. 101037084) funded by the European Commission granted under the call of the Horizon 2020 and within the framework of the CoastSpace project (ref. TED2021-130001B-C22) funded by MCIN/AEI/10.13039/501100011033 and by the "European Union NextGenerationEU/PRTR".

References

[1] Pye K., Tsoar H. (1990) - *Aeolian sand and sand dunes*. London: Unwin Hyman.

[2] Hesp P.A. (2002) - *Foredunes and blowouts: initiation, geomorphology and dynamics*. Geomorphology, 48, 245-268. DOI: 10.1016/S0169-555X(02)00184-8

[3] Bishop S.R., Momijib H., Carretero-González R., Warren A. (2002) - *Modelling Desert Dune Fields Based on Discrete Dynamics*. Discrete Dynamics in Nature and Society, Vol. 7 (1): 7-17 DOI: 10.1080/10260220290013462

[4] Carter R. W. G., Hesp P. A., Nordstrom K. F. (1990) - *Erosional landforms in coastal dunes*. In Nordstrom K. F., Psuty N. P., Carter R. W. G. (Ed.), *Coastal dunes: form and process*, pp. 217-250. Chichester: Wiley.

[5] Garcia-Lozano C., Pintó J., Daunis-i-Estadella P. (2018) - Changes in coastal dune systems on the Catalan shoreline (Spain, NW Mediterranean Sea). Comparing dune landscapes between 1890 and 1960 with their current status. Estuarine, Coastal and Shelf Science, 208, 235-247. DOI: 10.1016/j.ecss.2018.05.004

[6] Gómez-Pina G., Muñoz-Pérez J.J., Ramírez J.L, Ley C. (2002) - *Sand dune management problems and techniques, Spain*, J. Coast. Res, 36(sp1), 325-332.

[7] Pinna M.S., Bacchetta G., Cogoni D., Fenu G. (2019) - *Is vegetation an indicator for evaluating the impact of tourism on the conservation status of Mediterranean coastal dunes?* Science of the Total Environment 674: 255–263 DOI: 10.1016/j.scitotenv.2019.04.120

[8] Pintó J., Garcia-Lozano C., Varga D. (2023) - *Using dune-restricted species to assess the degree of natural diversity of dune systems on Mediterranean tourist coasts*. Ecological Indicators 147: 110004 DOI: 10.1016/j.ecolind.2023.110004

[9] Liu J., Wu J., Kimura R. (2023) - Evaluating the Sand-Trapping Efficiency of Sand Fences Using a Combination of Wind-Blown Sand Measurements and UAV Photogrammetry at Tottori Sand Dunes, Japan. Remote Sens., 15, 1098. DOI: 10.3390/rs15041098

[10] Roig-Munar F.X., Garcia-Lozano C., Pintó J., Martín-Prieto J.A. (2020) - *Spatiotemporal evaluation of the geomorphological state of beach-dune systems using management criteria*. Land Degradation and Development 31(18): 2901-2913 DOI: 10.1002/ldr.3677

[11] Durán R., Guillén J., Simarro G. (Eds.), (2019) - *X Jornadas de Geomorfología Litoral. Libro de ponencias*. Castelldefels, 4-6 septiembre 2019.

[12] Gravens M. B., Ebersole B. A., Walton, T., Wise R. (2002) - *Beach fill design. Coastal Engineering Manual. Part V*. Coastal Project Planning and Design.

[13] Huang W.P., Yim J.Z. (2014) - *Sand dune restoration experiments at Bei-Men Coast*, Taiwan, Ecological Engineering, 73 (409-420). DOI: 10.1016/j.ecoleng.2014.09.038