

The possible influence of sea level rise on the precarious dunes of Devesa del Saler Beach, Valencia, Spain

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Abstract

The Saler Beach dune field in Spain was partially destroyed between 1970 and 1973 due to building development. Presently great efforts to restore some dunes has begun. The possible consequence of a sea level rise for the Saler dune field is discussed according to different scenarios.

The study area

The Saler Beach (Fig. 1) is part of the beach barrier which closes the Valencia lagoon. The marsh extends for about 223 km². The lagoon is separated from the sea by a beach barrier about 30 km in length and 500-1,250 m in width. The beach barrier extends from the Turia River in the north to the cliffs of Cape of Cullera in the south. The southern extension of the barrier initially evolved as a recurved spit. This is indicated by the existence of two successive hooks (Rossello 1969). Close to these hooks are two natural inlets (Perello and Perellonet) and another one which is completely artificial. In the south near the Perello inlet the beach barrier reaches its minimum width, whereas at its two ends its width is maximum. The southern sector of the beach barrier does not display any recurves, but is a linear feature of a slightly increasing width from the north to the south indicating surplus of the littoral spit which is trapped by the presence of the Cape of Cullera. The final close of the beach barrier was produced about 6,000 BP (Sanjaume 1985).

Before the 1970's the northern part of the beach

barrier contained an important dune field. There were two large dune groups with slightly contrasting characteristics and separated by a wide longitudinal depression: (i) the outer group was composed of a few dune ridges parallel to the coast. The active foredune was separated from the other ridges by a swale. They were oriented parallel to the shoreline and thus they required prevailing **E-W** winds for their formation. The dunes were asymmetrical, narrow and they reached 9 m high. (ii) The inner group presented a much more regular morphology. Transverse ridge trends prevailed, which suggests a wind regime from the NE. The height was less than that of the outer group and the ridges were somewhat more symmetrical and of greater width (Sanjaume 1988).

The dynamic characteristics of this area are as follows:

- In the Valencia coasts the tide range is less than 20 cm (Margalef and Herrera 1961).
- A marked seasonal pattern of western winds in winter and eastern winds in summer. Spring and fall are transitional seasons (Sanjaume 1985).
- According to the wave regime, littoral drift is

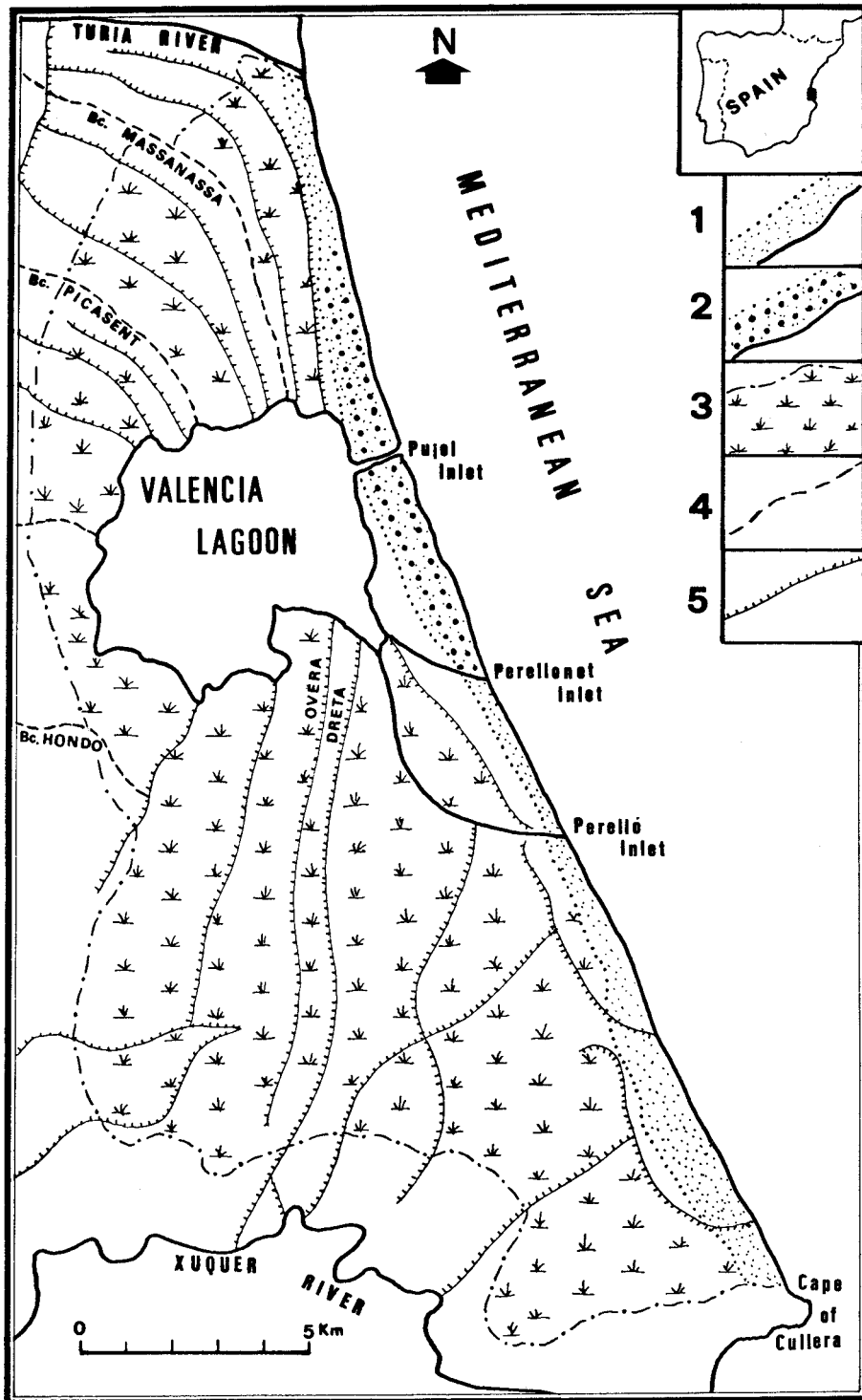


Fig. 1. Situation of the studied area. 1. Beach barrier. 2. Dune field. 3. Marshy area (ancient lagoon). 4. Ephemeral streams. 5. Irrigation channels.

Table 3. Frequencies of stones in different size classes at sampling stations along five hillside stripes at the Lawrence Memorial Grassland Preserve, Oregon.

Stripe	Station	Size classes (cm)					χ^2*	DF	P	Mean diameter (cm)
		<2	2–5	5–10	10–25	>25				
#1	1	7	15	24	14	0	41.57	4	<0.001	8.08
	2	4	12	26	18	0	44.72	4	<0.001	9.27
	3	7	5	36	12	0	31.00	4	<0.001	8.41
	4	0	9	53	18	0	20.15	4	<0.001	9.30
	5	1	15	55	9	0	25.04	4	<0.001	7.79
	Total	19	56	194	71	0	36.65	12	<0.001	8.57
#2	1	0	24	30	26	0	49.62	4	<0.001	9.55
	2	0	19	42	17	2	16.12	4	<0.01	9.42
	3	5	14	36	5	0	24.94	4	<0.001	6.86
	4	3	12	24	21	0	31.64	4	<0.001	9.88
	5	3	8	49	19	1	28.43	4	<0.001	9.61
	Total	11	77	181	88	3	37.16	12	<0.001	9.14
#3	1	0	43	32	5	0	6.49	4	NS	5.98
	2	7	28	33	5	0	37.06	4	<0.001	7.03
	3	7	32	33	8	0	10.43	4	<0.05	6.33
	4	1	27	30	21	1	15.57	4	<0.01	9.07
	5	7	12	6	15	0	36.67	2	<0.001	8.91
	Total	22	142	134	61	1	53.32	12	<0.001	7.30
#4	1	3	9	33	15	0	26.61	4	<0.001	9.08
	2	10	19	25	6	0	14.81	4	<0.01	6.15
	3	4	13	21	22	0	22.12	4	<0.001	9.87
	4	5	11	31	13	0	12.07	4	<0.05	8.39
	5	2	9	29	19	1	23.80	4	<0.001	10.35
	Total	24	61	139	75	1	27.51	12	<0.01	8.77
#5	1	3	10	37	10	0	10.80	4	<0.05	9.08
	2	4	10	42	4	0	20.07	4	<0.001	7.07
	3	3	11	34	12	0	25.52	4	<0.001	8.44
	4	9	8	34	8	1	16.07	4	<0.01	7.82
	5	0	8	29	22	1	15.32	4	<0.01	11.13
	Total	19	47	176	56	2	31.77	12	<0.01	8.53

* χ^2 values for individual stations are for contingency tests of frequency of sizes versus depth at that station (data not given in table), those for stripe totals are for contingency tests of frequencies of stones in different size classes versus the five station positions for that stripe.

slopes. Depth was strongly correlated with slope steepness (Table 5), as well as with stripe width ($r = 0.692, p < 0.001$). Although maximum depths were recorded at middle to lowermost sampling stations, depth did not show significant variation among stations along stripes. Depth did not change appreciably where stripes crossed rock outcrops.

Angularity of stones varied from a scale value of 1 (sharply angular) to 4.5 (fully- to semi-rounded) and lichen cover varied from 1 (<5%) to 4

(65–95%) (Table 2). These two variables were strongly correlated ($r = 0.839, p < 0.001$). Angularity varied significantly among the five stripes ($F = 11.60, p < 0.001$) but not among stations from the top to the bottom of stripes. Angularity index was also negatively correlated with slope steepness (Table 5) and with the degree of sorting of stone sizes with depth ($r = -0.459, p < 0.05$). The mean angularity index for 16 stations above outcrop locations (including all stations on stripes

Table 4. Biotic characteristics of hillside stone stripes sampled at the Lawrence Memorial Grassland Preserve, north-central Oregon.

	Stripe #1	Stripe #2	Stripe #3	Stripe #4	Stripe #5
Pocket gopher heaps					
Stn. 1	1	1	3	11	4
2	8	0	0	6	0
3	2	0	2	22	5
4	5	1	1	15	4
5	6	1	0	9	4
<i>Lomatium cous</i> (m⁻²)					
Stripe bed					
Stn. 1	1.7	0	0	0	1.0
2	20.0	0	0	0	3.4
3	20.2	0.6	0	0	0
4	17.4	0	0	5.7	3.3
5	0	0	0	10.9	0.9
Stripe border					
Stn. 1	2.2	0	0	1.2	0.2
2	0.8	0	0	5.0	3.5
3	2.2	0	0	1.5	2.5
4	0	0	0	2.5	4.2
5	0.2	0	0	3.2	0.8
<i>Lomatium minus</i> (m⁻²)					
Stripe bed					
Stn. 1	0	0	0	17.8	2.0
2	0	0	0	10.5	8.2
3	0	0	2.2	7.9	9.0
4	0	0	0	5.2	3.9
5	0	0	0	0	0.8
Stripe border					
Stn. 1	0	0	0	0	0
2	0	0	0	0	0.2
3	0	0	0	1.5	1.0
4	1.5	0	0	0	0
5	0	0	0	0	0

without outcrops) was 3.38, whereas for 9 stations below outcrops the mean was **1.95**; these values showed a highly significant difference by the Mann-Whitney U Test (Table 5).

Lichen cover varied among stripes ($F = 16.45$, $p < 0.001$) but not with location along stripe. The lichen cover index was likewise negatively correlated with slope steepness (Table 5). The mean lichen cover index for stations above outcrops (16) was **4.00**, and that for stations below outcrops (9) 1.67, a difference likewise highly significant by a Mann-Whitney U Test (Table 5).

Sorting of stones by size was tested by a χ^2 contingency analysis of frequency of stones of various size classes versus depth. Size-sorting, with larger stones more abundant near the surface and smaller stones more common in deeper layers, was significant in all but 1 of the **25** locations sampled (Table 3). In general, sorting was weaker when the mean diameter of stones at the sampling site was smaller than average for the site. The intensity of sorting was not clearly related to many other variables. Sorting was negatively correlated with angularity of stones ($r = -0.459$, $DF = 24$, $p < 0.05$),

Table 5. Results of tests of predictions of the four hypotheses of origin of stone stripes on hillsides of the Columbia Plateau, as outlined in Table 1. Predictions unique to a specific hypothesis are italicized. Symbols without parentheses indicate support of the prediction, those with parentheses indicate opposition. The symbol '+' indicates support by qualitative observations only.

Quantitative characteristic		Hypotheses			
		Erosion	Solifluction/soil creep	Outcrop weathering	Pocket gopher
Stripe width	U – M – L	(NS)	(NS)	+	
	Outcrop			+	
	Heaps				($r = -0.509, p < 0.05$)
Stripe depth	U – M – L	(NS)	(NS)	+	
	Slope	$r = 0.719, p < 0.001$			
	Outcrop			(NS)	
	Heaps				($r = -0.455, p < 0.05$)
Stone size	U – M – L	(NS)	NS	(NS)	NS
Stone sorting	U – M – L	(NS)	(NS)	(NS)	(NS)
	Depth				(NS)
Angularity	U – M – L	NS	NS		NS
	Slope		($r = -0.652, p < 0.01$)	$r = -0.652, p < 0.01$	
	Outcrop			$z = 3.41, p < 0.001$	
	Heaps				$r = 0.494, p < 0.05$
Lichen cover	U – M – L	NS			NS
	Slope		$r = -0.638, p < 0.01$	$r = -0.638, p < 0.01$	
	Outcrop			$z = 4.08, p < 0.001$	
	Heaps				(NS)
<i>Lomatium</i>	Heaps				$r = 0.665, p < 0.01$

and was most consistently strong on Stripes #1 and #2 on south-facing slopes (Table 3).

The distribution of stone sizes for all depths combined varied significantly among the five sampling stations for all five stripes (Table 3). The patterns contributing to these significant χ^2 contingency values differed for the individual stripes. Excesses of stones less than 5 cm in diameter at the upper three stations and excesses of stones larger than 5 cm at the lower two stations were exhibited for 16 of the 25 comparisons of individual station data with expectations. Stones greater than 5 cm in diameter were more frequent than expected at the lowermost station in four of the five stripes. The percentage of stones in the smallest size class (<2 cm diameter) was negatively correlated with slope ($r = -0.470, p < 0.05$). Stone size (mean maximum diameter) did not vary significantly among the stripes or among stations along stripes.

Pocket gopher heaps were numerous in the zone bordering Stripes #1, #4, and #5, but were scarce in the zones bordering Stripes #3 and #4, which were on steep slopes (Table 4). Numbers of heaps showed

a strong negative correlation with slope steepness ($r = -0.685, p < 0.001$). Numbers of heaps also showed weak negative correlations with stripe width and depth (Table 5), and a positive correlation with angularity index of stones (Table 5). No heaps were observed within the sorted stone beds of the stripes themselves.

Lomatium cous and *L. minus* were almost completely absent from the stone beds and adjacent soil of Stripes #2 and #3 on steep slopes (Table 4), which were also the deepest stripes. *Lomatium cous* showed highly variable abundance in the other three stone stripes, and was present in low to moderate density in areas adjacent to these stripes. The abundance of *L. cous* in the stripes themselves showed little relation to other variables. Total numbers of plants were negatively correlated with stripe width and depth ($r = -0.456$ and -0.476 , respectively; $p < 0.05$). Numbers of plants in fruit were positively correlated with the degree of sorting of stones ($r = 0.551, p < 0.05$). The abundance of *L. cous* in the zone bordering stripes, however, showed strong ($p < 0.001$) negative correlations

with slope steepness ($r = -0.875$), angularity of stones ($r = -0.692$), and stripe depth ($r = -0.671$), a moderately strong ($p < 0.01$) positive correlation with lichen cover of stones ($r = 0.544$), and a weak ($p < 0.05$) negative correlation with stripe width ($r = -0.476$). Pocket gopher activity, as evidenced by the abundance of heaps bordering the stripe, showed no relation to the abundance of *L. cous* in the stripe itself, but was positively correlated with the abundance of non-fruiting ($r = 0.867, p < 0.001$) and total ($r = 0.620, p < 0.01$) plants in the zone bordering the stripe.

Lomatium minus occurred in abundance only in Stripes #4 and #5, and was almost completely absent from areas outside the sorted stone beds of the stripes themselves (Table 4). This species was abundant in several sampling locations from which *L. cous* was absent. When data for *L. minus* and *L. cous* were combined, the abundance of pocket gopher heaps was positively correlated with *Lomatium* abundance in both the stripe (Table 5) and stripe border zones ($r = 0.588, p < 0.01$).

Discussion

None of the four hypotheses of origin of the stripes was supported fully by the sampling data (Table 5).

The positive correlation between slope steepness and stripe depth supported the erosion hypothesis, but depth did not show the consistent pattern of being greatest at stations near the stripe mid-zone, as predicted by this hypothesis. Lichen cover was not less at the upper and lower ends of stripes than in the middle zone, as predicted by this hypothesis, nor was vertical sorting of stones by size greatest near the bottom of stripes. Furthermore, although small stones tended to be more abundant at upper stations in stripes, they were not more abundant at the lowest stations than near the middle of the stripe, as predicted by the erosion hypothesis.

The pattern of stripe width and depth from upper to lower end of the stripes contradicted the prediction of the solifluction/soil creep hypothesis, as did the fact that major differences in angularity of stones occurred at different sampling locations. Lichen cover was negatively correlated with slope

steepness, however, as expected by this hypothesis.

The outcrop weathering hypothesis was supported by several stripe characteristics. Stripe width and depth were greatest at or below the stripe mid-elevation, and stripes increased in width below outcrops; both trends supported this hypothesis. The strong correlations of slope steepness with angularity of stones and lichen cover, along with the highly significant differences in angularity and lichen cover above and below outcrops, likewise supported this hypothesis. The predicted increase in stripe depth below outcrops was not observed. The tendency for larger stones to predominate at lowermost sampling stations of four stripes opposed this hypothesis. The lack of outcrops in association with Stripe #4 and with the upper ends of Stripes #1 and #5, in addition, indicate that this hypothesis cannot account for stripe formation in all situations.

The pocket gopher hypothesis was supported by the lack of significant trends in lichen cover, angularity, mean size and degree of vertical sorting of stones with location along stripes. The positive relation between pocket gopher activity and angularity of stones also supported this hypothesis. Pocket gopher activity, as indexed by the number of heaps adjacent to stripes, was positively correlated with abundance of food plants both in the stripe itself and in the zone bordering the stripe, as predicted by the hypothesis. The abundance of pocket gopher heaps was negatively related to stripe width and depth, however, in direct opposition to the prediction of this hypothesis.

Of the four hypotheses, the solifluction/soil creep hypothesis was not supported by any of the four predictions unique to this hypothesis. The erosion hypothesis was supported by only one of the four predictions unique to it. The outcrop weathering hypothesis, however, was partially or fully supported by five of its seven unique predictions. The pocket gopher hypothesis was supported by four of eight unique predictions. These results indicate that the origin of hillside stone stripes involves at least three of the postulated mechanisms.

We conclude that the origin of stripes on gentle upper slopes is primarily the result of pocket gopher tunneling activity. Pocket gopher activity was greatest in areas of abundance of *Lomatium* species,

both in and adjacent to the stripes, and these areas of abundance were concentrated in narrow, shallow stripe sections on gentle slopes. Cox (1990) has shown that the orientation of bare stone beds perpendicular to the contour on mounded upper slopes can be accounted for by the influence of slope on soil translocation by pocket gophers. These stripes also serve as channels of water flow, which probably also contribute to stripe maintenance by the removal of soil fines. The pattern of soil excavation from tunnels beneath stone beds and deposition at bed margins, as noted by Cox and Allen (1987) for beds associated with Mima mounds, creates the sharp borders to these stripes. Erosion seems to be of secondary importance, however, since it does not lead to predictable patterns of concentration of the smallest stones in lower sections of the stripe.

When stripes originate below outcrops, or cross them downslope, the character of the stripe changes substantially. Stripe width increases, the angularity of stones increases, and lichen cover declines, indicating that outcrops actively feed new stones into the stripe. Although pocket gopher activity is shown in areas bordering stripes below outcrops, the abundance of *Lomatium* food plants in these locations decreases, probably because the depth of the stripes in these situations becomes too great for these plants. On the steepest slopes of Stripes #2 and #3, for example, both *Lomatium* plants and pocket gopher heaps were very scarce. The action of pocket gophers in these situations may only be to contribute to the sharply bordered edge of the stripe. Thus, with increasing slope steepness and the crossing of an outcrop, weathering of outcrops and downhill movement of stones by mass wasting becomes the dominant stripe process. Pyrch (1973) documented mean downslope rates of stone movement equal to about 9.8 mm yr⁻¹ in this same general region. With reduced importance of pocket gopher activity, erosion may play a greater role in maintaining the stripes free of soil fines.

We conclude that stripe formation and maintenance in the Columbia Plateau region involves the dominant forces of pocket gopher tunneling on upper slopes and outcrop weathering processes on lower slopes, with erosion playing a secondary role in both locations. Stripes thus appear to be formed

and maintained by processes presently operating, and do not appear to be relic features of Pleistocene glacial periods. The shallow soils overlying basaltic bedrock in this region, in fact, do not permit the free convection mechanism of origin of sorted stone polygons and stripes (Ray *et al.* 1983; Gleason *et al.* 1986; Krantz *et al.* 1988) to operate. We suggest that pocket gopher activity is a widely important mechanism in the origin of stone nets and stripes in western North America, and that it should be considered in regard to other stripes considered to be relicts of past cold climates (*e.g.*, Krantz *et al.* 1988, p. 71).

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