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Sand Dune Species Distribution and Size Variations in Two Areas Inside a Natural Protected Area Subjected to Different Human Disturbance

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ABSTRACT

Sand dune species were analyzed across two areas included in the "Roman Coastal State Nature Reserve" (Italy): Ostia (O) and Marina di Palidoro (P). Significant variations in species distribution, dry mass and size over the gradient from the water-edge toward the inland between O and P were observed. Species colonize O, on an average, at 79 m from the water-edge extended along the gradient toward the inland over a length of 26 m. PD is 40.8 ± 9.9 plants·m^{-2}. *Ononis variegata* and *Elymus farctus* have the highest PD (15.4 ± 1.3 plants·m^{-2}), followed by *Silene colorata* and *Sporobulus pungens* (4.3 ± 3.9 plants·m^{-2}), by *Cakile maritima*, *Echinophora spinosa*, *Eryngium maritimum*, *Ammophila arenaria*, *Anthemis maritima*, *Cyperus capitatus*, *Medicago marina* and *Calystegia soldanella* (<0.5 plants·m^{-2}), with *C. soldanella* having the lowest PD (0.02 plants·m^{-2}). On an average, in P, the species colonize the dune at 17 m from the water-edge for a length of 46 m toward the inland, PD is on an average 21.5 ± 16.1 plants·m^{-2}. *S. pungens*, *E. farctus and O. variegata* have the highest PD (6.0 ± 2.4 plants·m^{-2}), followed by *C. capitatus* (2.1 ± 4.7 plants·m^{-2}), by *S. colorata* and *A. maritima* (0.4 ± 0.1 plants·m^{-2}) and by *E. spinosa*, *E. maritimum*, *M. marina*, *Pancratium maritimum and C. soldanella* (0.2 plants·m^{-2}). The results underline a larger species presence along the gradient from the water-edge toward the inland in P site compared to O site where, on the contrary, plants exclusively colonize the inner dune area due to the strong human disturbance which causes the foredune to become flat. Nevertheless, the presence of the most important autoctonous sand dune species (on an average, 15.3 ± 0.5 species) can provide information for restoring the perturbed dune areas when preparing management strategies considering that the maintenance of coastal areas depends on the maintenance of native species.

Keywords: Dune Vegetation; Human Disturbance; Plant Density; Organic Soil Matter

1. Introduction

Some critical factors affect the survival and distribution of coastal sand dune species which grow on a physiologically dried substrate characterised by a low mineral content [1-4]. A factor which contributes to select dune species is the climatic effect on sand movements [5,6] such as wind-speed entrainment thresholds for sand particles and salt burial [7,8]. With regard to species assemblage, dune-builder plants may grow on fore-dunes, burial-tolerant plants on inter-dunes and shrubs on stabilized dunes [9]. Morphological and physiological plant adaptations are important especially on fore-dunes [10-12] where few species are capable of withstanding the stress factors imposed by limited environmental resources and recurrent disturbance. On older dunes, where salt spray, nutrient and water are no longer exclusive limiting factors, competition for space and light may affect species richness [13-15]. Plant species presence is also related to organic matter which varies from water-edge toward the inland [11,13].

The ecological state of sea coasts is often critical worldwide [16]. In Europe most of the well conserved coastal dune areas are at present under protection [17] and are included in the EU Directive Habitat 92/43/CEE. Nevertheless, dunes are the most threatened habitats by the expansion of urban areas and the development of seaside tourism [9,18] leading to the fragmentation of vegetation and the disappearance of vegetation bands developing on mobile dunes [19]. Disturbance is defined as a stochastic event in opposition to environmental stress which is predictable and rather continuous [20].

Most common environmental stress factors are drought and soil nutrient deficiency [21]. Among human disturbance, infrastructure development is widespread on coasts in Europe. Furthermore, landscape fragmentation disrupts large scale geo-morphological processes [22] and mechanical damages through trampling reduce or even destroy vegetation [13]. Increased knowledge of plant species response to stress factors (*i.e.* climate, soil, anthropogenic interference) aims at the long-term land use planning to ensure sustainability of coastal resources while providing management flexibility for the future [23].

The main objective of this research was to compare the species presence in two areas included in a natural protected area developing along the Tyrrhenian coast near Rome and subjected to a different human disturbance. Considering the importance of biological diversity maintenance [24-27], we analyzed variations in sand dune species presence, dry mass and size over the gradient from the water-edge toward the inland.

2. Methods

2.1. The Study Area

The study was carried out in the year 2012 in the Roman Coastal State Nature Reserve (Italian decree of 1996) which extended for ca 43 Km along the Tyrrhenian coast near Rome (Italy). Two areas were selected: Ostia (41˚41'00"N 12˚22'39"E) and Marina di Palidoro (41˚54'43"N 12˚08'47"E) (**Figure 1**). Despite the two areas being under protection, in recent years they were subjected to human disturbance. In particular, Ostia (O) was a small populated city (85,301 people/km^2, data from Rome Municipality for the year 2010) where numerous buildings and bathing establishments were built in the last 50 years. Two sub-areas were selected for measurements: O_1 (41˚40'58"N, 12˚22'40"E) near a gully, extending along the coast line for ca 200 m, and O_2 (41˚40'37"N, 12˚23'14"E) near a bathing establishment, extending along the coastline for ca 400 m. At both O_1 and O_2 the sand dune appeared flat up to 70 - 80 m from the water-edge, followed by a mobile dune area characterised by a moderate slope of ca 6%, which finished with the fixed dune colonized by Mediterranean shrubs. The distance from the water-edge to the shrubby layer was 109 m and 100 m in O_1 and O_2, respectively. Dune species were present at 85 and 73 m from the water-edge in O_1 and O_2, respectively.

Marina di Palidoro (P) was characterized by a lower human disturbance than O because of few buildings and bathing establishments. Two sub-areas were selected in P for measurements: P_1 (41˚55'06"N, 12˚08'17"E) near the hospital Bambino Gesù, extending along the coast line for ca 1600 m, and P_2 (41˚54'43"N, 12˚08'46"E) near a block of flats, extending along the coast line for ca 700 m. In P_1 and P_2 the drift line and the foredune extended along the gradient from the water-edge toward the inland for ca 33 m and 41 m, respectively, was characterized by a moderate slope (ca 2%). Then it was followed by a mobile dune area extending for ca 20 m and 32 m in P_1 and P_2, respectively, and by the fixed dune with Mediterranean shrubs. The distance from the water-edge to the

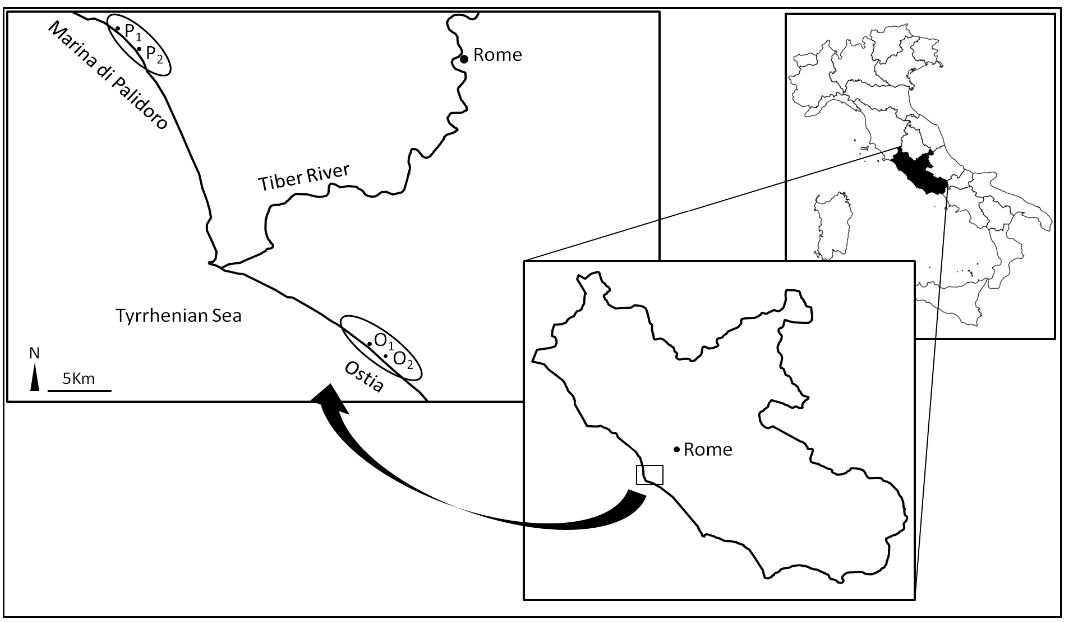

Figure 1. The two studied areas along the Thyrrenian coast near Rome, Ostia (O, 41˚41'00"N, 12˚22'39"E) and Marina di Palidoro (P, 41˚54'43"N, 12˚08'47"E), and the considered sub-areas (O_1, O_2, P_1 and P_2) are indicated.

shrubby layer was 53 m and 73 m for P_1 and P_2, respectively. Species were present at 20 and 15 m from the water-edge, in P_1 and P_2 respectively.

A transect oriented from the water-edge toward the inland was established in each of the selected sub-areas (O_1, O_2, P_1, P_2) for vegetation sampling. Along each transect, plots (10 × 10 m each) were established, 3 m apart, starting from the water-edge to the inland (*i.e.* Mediterranean shrubby). Plot numbers were established in relation to the extension in length of the dune from water edge toward the inland and to species presence. In each sub-area the first plot was established where the first species presence occurred. In particular, two plots were established in O_1 (O_{1a}, and O_{1b} at 85 and 98 m from the water edge, respectively), O_2 (O_{2a}, O_{2b} at 73 m and 86 m from the water edge, respectively), and in P_1 (P_{1a} and P_{1b} at 20 and 33 m from the water-edge, respectively), and four plots in P_2 (P_{2a}, P_{2b}, P_{2c} and P_{2d} at 15, 28, 41 and 54 m from the water-edge, respectively).

2.2. Climate and Microclimate

The selected areas were characterised by a Mediterranean type of climate. At O, the total annual rainfall was 589 mm, the mean minimum air temperature of the coldest months (January and February) was 4.8˚C and the mean maximum air temperature of the warmest months (July and August) was 29.1˚C (data from the Meteorological Station of Pratica di Mare, for the years 2000-2012) (**Figure 2**). At P, the total annual rainfall was 556 mm, the mean minimum air temperature of the coldest months (January and February) was 3.2˚C and the mean maximum air temperature of the warmest months (July and August) was 29.6˚C (data from the Meteorological Station of Fiumicino, for the years 2000-2012) (**Figure 2**). The dominant winds were from W and the others from S and SE. The mean yearly winds speed was 16.6 knots and 18.7 knots at O and P, respectively [28].

Microclimate was measured in the considered sub-areas at 20, 40, 60, 80, 100 m from the water-edge toward the inland, periodically (twice a month) during the study period. In each sampling occasion, air temperature (T, ˚C), relative air humidity (RH, %), total irradiance (I, μmol photon $m^{-2} \cdot s^{-1}$) and wind speed (W, m/s) were recorded at 50 cm from the sand level. On each sampling occasion, measurements were carried out at 12:00 a.m.

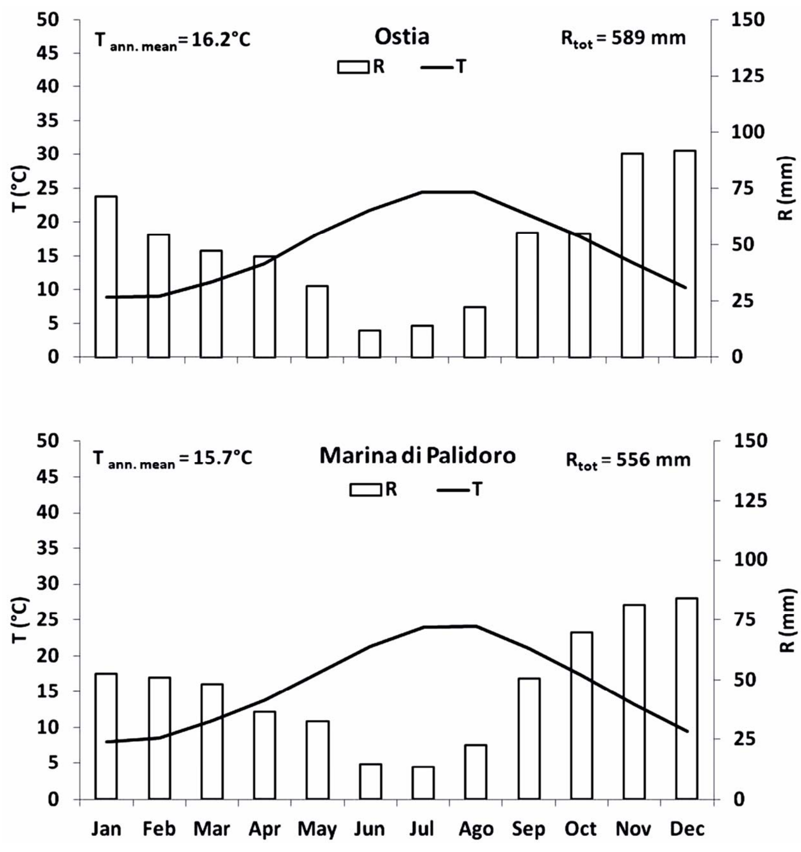

Figure 2. Climate diagrams of Ostia (O) and Marina di Palidoro (P) (data from the Meteorological Station of Pratica di Mare and of Fiumicino, respectively, for the period 2000-2011). Total monthly rainfall (R, mm, columns), mean monthly air temperature (T, ˚C, lines), annual mean temperature ($T_{ann.mean}$) and total annual rainfall (R_{tot}) are shown.

Air temperature and air humidity were measured by a thermo-hygrometer (HD8901, Delta Ohm, I), total irradiance by a radiometer (LI-185B with a 190SB Quantum Sensor, LI-COR, USA) and wind speed by an anemometer (LUTRON AM-4201).

2.3. Sand Characterization

Triplicate sand samples were collected in the considered sub-areas at 20, 40, 60, 80, 100 m from the water-edge, for determination of sand water content (SWC, %), pH, soil organic matter (SOM, %) content and total nitrogen (N, %) content. All sand samples were collected at the end of May (at least 5 days after the last rainfall) at a depth of 40 cm by a drill. Sand samples were transported immediately to the laboratory. Sand samples were air dried at room temperature and then passed through 2 mm sieve. SWC was determined on sand samples (500 g each) as fresh sand minus dry sand divided by dry sand percent, calculated after oven-dried at 90˚C to a constant mass. The pH was measured with a glass electrode in a suspension of sand in deionized water. SOM was determined colorimetrically with potassium dichromate, according to [29] and the N content by Kjeldahl method, according to [30].

2.4. Plant Species Presence and Plant Traits

Species presence was recorded in the considered plots from May to June, corresponding to the maximum plant biomass [31,32]. The number of plants per species was counted in each plot to calculate plant density (PD, individuals·m^{-2}).

Measurements of plant traits were carried out on representative plant species (5 plants per species in each plot) at the beginning of June. It included plant height (H, m), total plant volume per plot (V, cm^3·m^{-2}), total plant area per unit of covered area at sand level (PA, cm^2·m^{-2}) and total aboveground plant biomass (TPB, g·m^{-2}). Plant material was harvested, oven dried and then weighed to obtain dry mass (DM, g), according to [33]. TPB per species was calculated by multiplying DM and PD. H was defined as the maximum vertical distance from the sand level to the highest point of the plant. V was calculated by the volume of a cylinder, according to [34].

2.5. Statistical Analysis

The main gradients in species composition were extracted by ordination (principal coordinate analysis, PcoA) which was performed on the plot-to-plot dissimilarity matrix and calculated with the Jaccard coefficient for species presence and absence data.

Differences of the means for the considered traits were tested by one-way ANOVA, and *Tuke*y test for multiple comparisons. Kolmogorov-Smirnov and Levene tests were used to verify the assumption of normality and homogeneity of variances, respectively.

All statistical tests were performed by using Statistica 6.0 (Statsoft, USA). All data were shown as mean ± S.D.

3. Results

3.1. Microclimate and Sand Characterization

The microclimate of the considered sub-areas (P_1 and P_2 and O_1 and O_2) is shown in **Figure 3**. In all the considered sub-areas, T increased by 15% from water-edge to the inland, while RH and I decreased by 13%, 6% respectively (mean of P_1, P_2, O_1 and O_2). The wind (W) action decreased, on an average, 56% from water-edge toward the inland, both in O and P sub-areas.

The O and P sand characterization is shown in **Figure 4**. In the considered sub-areas, SWC and pH decreased on an average, 18% and 11% from the water-edge toward the inland, respectively, while SOM and N content increased more than 100% and 113%, respectively (mean of O and P).

3.2. Plant Traits

Data on species presence, PD, H, V, PA and TPB in the considered plots are shown in **Table 1**. The number of species was larger in P (15.5 ± 0.5, mean of P_1 and P_2 plots) than in O (14.5 ± 0.5, mean of O_1 and O_2 plots). A larger PD was monitored in $P_{1b,}$ and P_{2c}, (37.7 ± 3.1 plants·m^{-2}, mean value) and in O_{1b} and O_{2b} (48.8 ± 0.15 plants·m^{-2}, mean value) than in the other plots (22.1 ± 14.3 plants·m^{-2}, mean value). *Crucianella maritima* (PD = 0.53 plants·m^{-2}, mean value) was monitored only in P_{2d}. The plots farer from the water-edge had a higher H than those closer to it. In particular, H was on an average 59% higher in O_{1b} than in O_{1a} and 70% higher in O_{2b} than in O_{2a}. H was 41% higher in P_{1b} than in P_{1a}, and 74% higher in P_{2c} and P_{2d} than in P_{2a} and P_{2b}. On an average, PA was 82% larger in O_{1b} than in O_{1a} and 94% larger in O_{2b} than in O_{2a}. PA was 266% larger in P_{1b} than in P_{1a}, and 577% larger in P_{2c} and P_{2d} than in P_{2a} and P_{2b}. TPB ranged from 1145.8 g·m^{-2} (in O) to 1413.0 g·m^{-2} (in P) and it was the highest in O_{2b} (304.9 g·m^{-2}) among O plots, and in P_{2d} (394.4 g·m^{-2}) among P plots.

As regards to the species, *E. farctus* had the highest TPB and V (141.6 ± 62.2 g·m^{-2} and 19837 ± 8885 cm^3·m^{-2} respectively, mean of the considered P and O plots) and *Chamaesyce peplis* the lowest one (0.008 ± 0.010 g·m^{-2} and 1.9 ± 2.1 cm^3·m^{-2} respectively, mean of the considered P and O plots).

3.3. Principal Coordinate Analysis

PCoA extracted two factors accounting for 53.33% of the

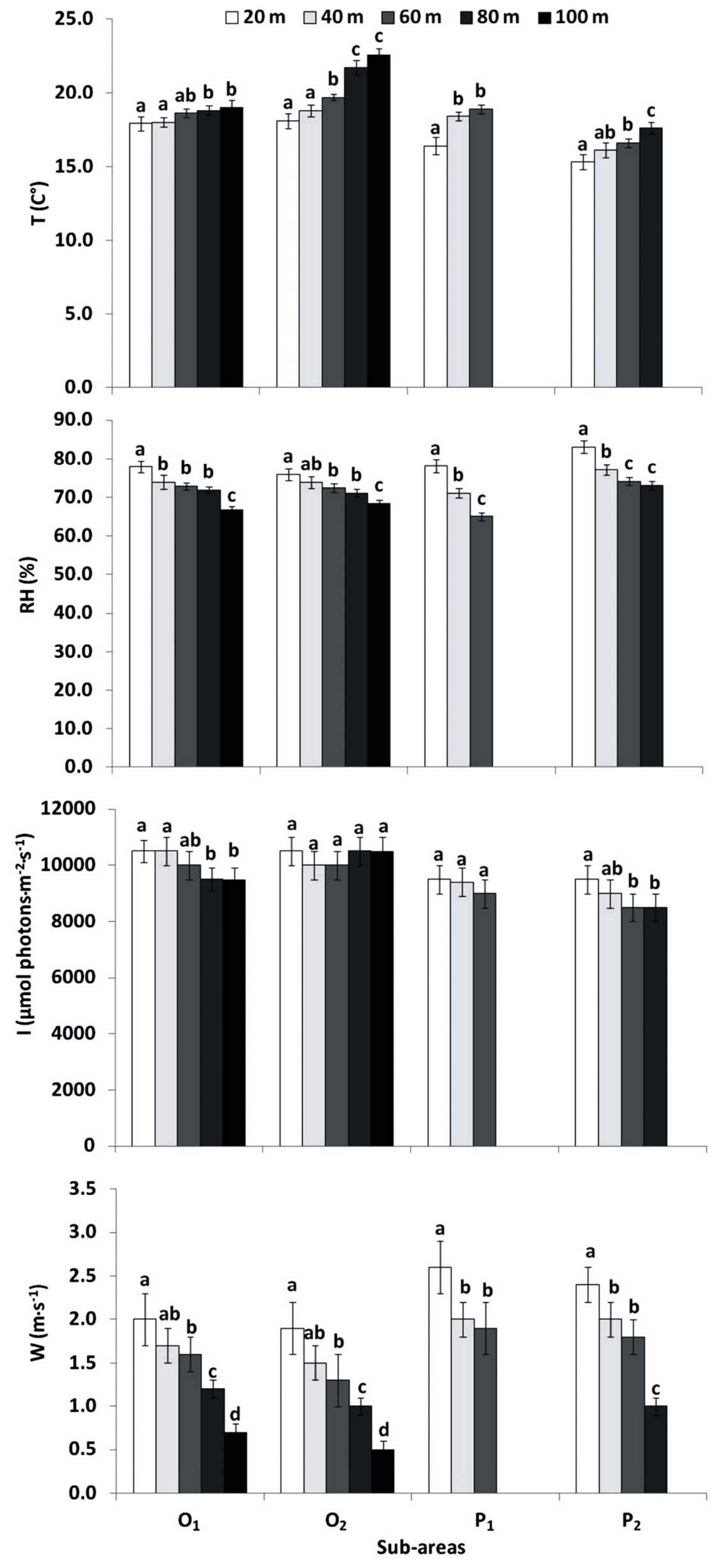

Figure 3. Air temperature (T, ˚C), relative air humidity (RH, %), total irradiance (I, µmol photons m^{-2}·s^{-1}) and wind speed (W, m·s^{-1}) measured at 50 cm from the sand level, at 12:00 a.m., in the considered sub-areas at Ostia (O_1, O_2) and at Marina di Palidoro (P_1 and P_2). Measurements were carried out at 20, 40, 60, 80, 100 m from water-edge. Mean values ± standard deviation are shown. For each sub-area different letters indicate significant differences among the distances over the gradient from the water-edge toward the inland.

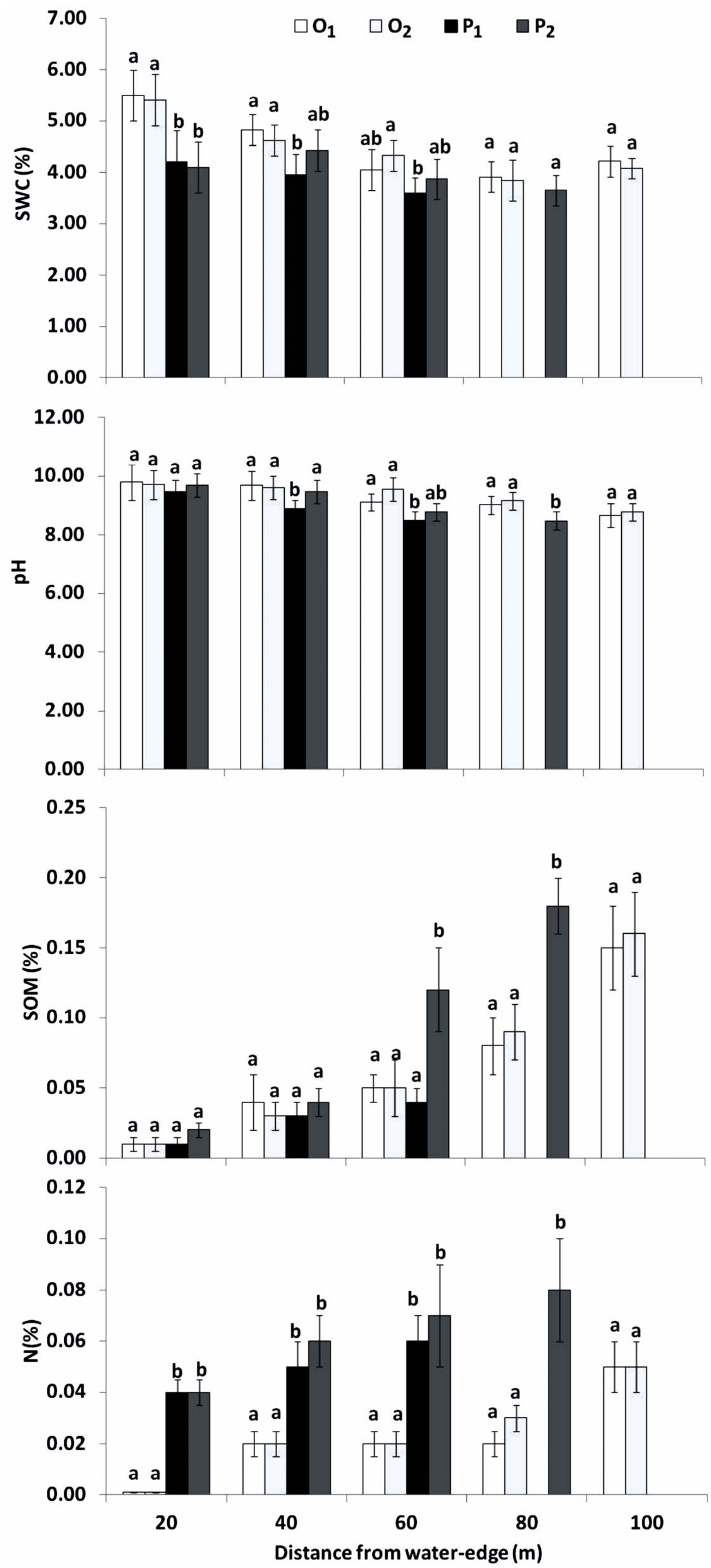

Figure 4. Sand water content (SWC, %), pH, soil organic matter (SOM, %) and total nitrogen content (N, %) collected in the considered sub-areas in Ostia (O_1, O_2) and Marina di Palidoro (P_1 and P_2) at 20, 40, 60, 80, 100 m from water-edge. Mean values ± standard deviation are shown. For each distance over the gradient from the water-edge toward the inland sub-area different letters indicate significant differences among the sub-areas.

Table 1. Data on species presence, plant density, plant height, plant area, plant volume and total plant biomass of the considered plots used in this study. For each species different letters indicate significant differences among the plots.

Distance (m)	85 - 95	98 - 108	73 - 83	86 - 96	20 - 30	33 - 43	15 - 25	28 - 38	41 - 51	54 - 64
Species / Plot	O_{1a}	O_{1b}	O_{2a}	O_{2b}	P_{1a}	P_{1b}	P_{2a}	P_{2b}	P_{2c}	P_{2d}
	PD (plant·m^{-2})		PD (plant·m^{-2})		PD (plant·m^{-2})		PD (plant·m^{-2})			
Cakile maritima **Scop.**	0.01 a	-	-	0.01 a	0.02 a	-	0.88 b	-	0.02 a	-
Echinophora spinosa **L.**	0.05 a	0.12 b	0.07 a	0.11 b	0.02 a	0.07 a	-	0.02 a	0.16 c	0.25 d
Eryngium maritimum **L.**	-	0.01 a	-	0.10 b	0.07 ab	0.03 a	-	0.15 c	-	0.15 c
Elymus farctus **(Viv.) Runemark ex Melderis**	18.60 a	12.09 b	20.70 a	14.00 b	11.85 b	5.15 c	-	9.00 d	13.15 b	5.04 c
Ammophila arenaria **(L.) Link**	-	1.16 a	-	0.80 ac	-	0.14 b	-	-	0.54 c	-
Anthemis maritima**L.**	0.26 a	0.39 b	0.14 a	0.58 b	0.05 c	1.36 d	-	-	0.18 a	0.59 b
Cyperus capitatus **Vand.**	-	0.59 ab	-	0.31 a	-	0.79 b	-	-	-	11.75 c
Ononis variegata**L.**	0.14 a	28.3 b	-	29.40 b	-	13.25 c	-	-	-	6.02 d
Medicago marina**L.**	-	0.15 a	0.02 b	0.02 b	-	0.04 b	-	-	-	0.12 a
Crucianella maritima**L.**	-	-	-	-	-	-	-	-	-	0.53
Calystegia soldanella**(L.) R. Br.**	0.02a	-	-	-	-	0.03 a	-	-	-	0.06 b
Sporobolus pungens**(Schreb.) Kunth**	16.55a	2.85 b	7.85 c	1.20 d	-	13.00 e	-	0.15 f	25.75 g	5.50 c
Silene colorata**Poir.**	0.71a	3.10 b	0.04 c	2.45 b	-	0.92 d	-	-	-	1.43 e
Pancratium maritimum**L.**	-	0.01a	-	0.01 a	0.03 ac	0.71 b	-	-	0.01 a	0.05 c
Salsola kali**L.**	0.12a	-	0.01 b	-	0.02 b	-	0.07 c	0.12 a	0.04 bc	-
Chamaesyce peplis **(L.) Prokh.**	0.01a	-	0.01 a	-	0.01 a	-	-	-	0.08 b	-
Total	**17.54**	**48.76**	**28.82**	**48.96**	**12.04**	**35.46**	**0.07**	**9.43**	**39.91**	**31.46**
	H (cm)		H (cm)		H (cm)		H (cm)			
Cakile maritima **Scop.**	22.0 a	-	-	35.0 b	11.5 c	-	16.5 d	-	19.3 d	-
Echinophora spinosa **L.**	40.6 a	36.5 a	29.5 b	29.1 b	10.8 c	21.0 d	-	28.5 b	26.6 b	17.2 e
Eryngium maritimum **L.**	-	22.5 a	-	26.4 b	21.8 ac	19.3 c	-	12.3 d	-	24.9 ab
Elymus farctus **(Viv.) Runemark ex Melderis**	43.0 a	43.0 a	40.5 a	64.8 b	43.7 a	43.5 a	-	53.7 c	44.0 a	41.0 a
Ammophila arenaria **(L.) Link**	-	92.5 a	-	105.0 b	-	28.0 c	-	-	108.1 b	-
Anthemis maritima**L.**	16.3 a	16.9 ab	19.5 b	14.6 a	13.1 a	17.4 ab	-	-	20.2 b	13.3 a
Cyperus capitatus **Vand.**	-	39.0 a	-	37.8 a	-	36.0 a	-	-	-	44.5 b
Ononis variegata**L.**	10.1 a	11.5 a	-	9.5 a	-	9.5 a	-	-	-	11.5 a
Medicago marina**L.**	-	12.4 a	7.8 b	9.3 b	-	12.6 a	-	-	-	15.6 a
Crucianella maritima**L.**	-	-	-	-	-	-	-	-	-	18.2
Calystegia soldanella**(L.) R. Br.**	3.5 a	-	-	-	-	3.5 a	-	-	-	6.5 b
Sporobolus pungens**(Schreb.) Kunth**	19.0 ac	19.0 ac	17.0 a	16.0 a	-	10.5 b	-	10.1 b	11.0 b	21.5 c
Silene colorata**Poir.**	14.0 a	15.5 a	20.0 b	14.5 a	-	14.0 a	-	-	-	20.0 b
Pancratium maritimum**L.**	-	15.5 a	-	17.0 a	10.6 b	28.5 c	-	-	38.0 d	41.7 d
Salsola kali**L.**	10.4 a	-	9.8 a	-	2.3 b	-	2.0 b	2.3 b	2.4 b	-
Chamaesyce peplis **(L.) Prokh.**	4.0 a	-	4.5 a	-	2.0 b	-	-	-	2.4 b	-
Mean	**18.3**	**29.5**	**18.6**	**31.6**	**14.5**	**20.3**	**9.3**	**21.4**	**30.2**	**23.0**
	PA (cm^2·m^{-2})		PA (cm^2·m^{-2})		PA (cm^2·m^{-2})		PA (cm^2·m^{-2})			
Cakile maritima **Scop.**	15.00 a	-	-	13.35 a	4.00 b	-	352.00 c	-	81.63 d	-
Echinophora spinosa **L.**	136.45 a	321.71 b	99.63 c	158.77 d	3.14 e	22.02 f	-	4.50 e	232.55 g	109.86 c
Eryngium maritimum **L.**	-	4.02 a	-	231.43 b	22.79 c	10.59 c	-	49.28 d	-	104.26 e
Elymus farctus **(Viv.) Runemark ex Melderis**	672.00 a	423.15 b	724.50 a	490.00 b	414.75 b	180.25 c	-	315.00 d	460.25 b	176.40 c
Ammophila arenaria **(L.) Link**	-	29.05 a	-	20.00 a	-	3.38 b	-	-	181.03 c	-
Anthemis maritima**L.**	413.90 a	524.19 b	358.68 a	654.05 c	187.08 d	1415.94 e	-	-	626.01 c	887.86 f
Cyperus capitatus **Vand.**	-	28.08 ab	-	14.64 a	-	37.68 b	-	-	-	564.00 c

Continued

***Ononis variegata*L.**	41.99 a	707.50 b	-	735.00 b	-	331.25 c	-	-	-	138.00 d
***Medicago marina*L.**	-	507.74 a	12.56 b	97.50 c	-	104.8 c	-	-	-	495.73 a
***Crucianella maritima*L.**	-	-	-	-	-	-	-	-	-	498.45
***Calystegia soldanella*(L.) R. Br.**	0.29 a	-	-	-	-	1.05 a	-	-	-	11.00 b
***Sporobolus pungens*(Schreb.) Kunth**	136.80 a	22.80 b	62.80 c	9.60 d	-	104.00 e	-	1.20 f	206.00 g	44.00 c
***Silene colorata*Poir.**	4.26 a	18.60 b	0.21 c	14.70 b	-	5.49 a	-	-	-	8.55 d
***Pancratium maritimum*L.**	-	1.63 a	-	2.72 a	1.47 a	101.52 b	-	-	14.23 c	65.89 d
***Salsola kali*L.**	0.82 a	-	0.08 b	-	0.10 b	-	1.48 c	0.96 a	0.38 d	-
***Chamaesyce peplis* (L.) Prokh.**	0.16 a	-	0.29 a	-	0.28 a	-	-	-	2.12 b	-
Total	**1421.66**	**2588.46**	**1258.76**	**2441.75**	**633.61**	**2317.96**	**353.48**	**370.94**	**1804.20**	**3104.01**
	V ($cm^3 \cdot m^{-2}$)		V ($cm^3 \cdot m^{-2}$)		V ($cm^3 \cdot m^{-2}$)		V ($cm^3 \cdot m^{-2}$)			
***Cakile maritima* Scop.**	330.0 a	-	-	467.1 b	46.0 c	-	5808.0 d	-	1571.3 e	-
***Echinophora spinosa* L.**	5543.3 a	11742.2 b	2941.2 c	4626.5 d	33.8 e	461.5 f	-	128.3 g	6194.0 h	1892.8 i
***Eryngium maritimum* L.**	-	90.5 a	-	6114.4 b	495.8 c	204.8 d	-	606.9 e	-	2598.5 f
***Elymus farctus* (Viv.) Runemark ex Melderis**	28896.0 a	18195.5 b	29342.3 a	31752.0 a	18106.8 b	7840.9 c	-	16915.5 b	20251.0 b	7232.4 c
***Ammophila arenaria* (L.) Link**	-	2686.7 a	-	2100.0 a	-	94.5 b	-	-	19576.7 c	-
***Anthemis maritima*L.**	6736.7 a	8862.5 b	7008.6 a	9569.7 b	2447.6 c	24605.4 d	-	-	12629.8 e	11801.1 e
***Cyperus capitatus* Vand.**	-	1095.1 ab	-	552.7 b	-	1356.5 a	-	-	-	25098.0 c
***Ononis variegata*L.**	425.6 a	8136.3 b	-	6982.5 b	-	3146.9 c	-	-	-	1587.0 d
***Medicago marina*L.**	-	6315.7 a	97.3 b	901.9 c	-	1320.4 d	-	-	-	7736.9 a
***Crucianella maritima*L.**	-	-	-	-	-	-	-	-	-	9090.7
***Calystegia soldanella*(L.) R. Br.**	1.0 a	-	-	-	-	3.7 a	-	-	-	71.5 b
***Sporobolus pungens*(Schreb.) Kunth**	2599.2 a	433.2 b	1067.6 c	153.6 d	-	1092.0 c	-	12.1 e	2266.0 f	946.0 c
***Silene colorata*Poir.**	59.6 a	288.3 b	4.2 c	213.2 b	-	76.9 a	-	-	-	171.0 d
***Pancratium maritimum*L.**	-	25.2 a	-	46.2 a	15.6 a	2893.3 b	-	-	540.7 c	2747.5 b
***Salsola kali*L.**	8.6 a	-	0.8 b	-	0.2 b	-	3.0 c	2.3 c	0.9 b	-
***Chamaesyce peplis* (L.) Prokh.**	0.6 a	-	1.3 a	-	0.6 a	-	-	-	5.1 b	-
Total	**44600.6**	**57871.1**	**40463.2**	**63479.7**	**21146.4**	**43096.7**	**5811.0**	**17665.0**	**63035.3**	**70973.5**
	TPB ($g \cdot m^{-2}$)		TPB ($g \cdot m^{-2}$)		TPB ($g \cdot m^{-2}$)		TPB ($g \cdot m^{-2}$)			
***Cakile maritima* Scop.**	0.250 a	-	-	0.222 a	0.067 b	-	5.870 c	-	1.361 d	-
***Echinophora spinosa* L.**	4.107 a	9.683 b	2.999 c	4.779 a	0.120 e	0.662 f	-	0.120 e	7.000 g	3.307 c
***Eryngium maritimum* L.**	-	0.257 a	-	14.808 b	1.460 c	0.678 ac	-	3.155 d	-	6.671 e
***Elymus farctus* (Viv.) Runemark ex Melderis**	216.318 a	140.607 b	240.741 a	162.820 b	137.816 b	59.895 c	-	104.67 d	152.935 b	58.615 c
***Ammophila arenaria* (L.) Link**	-	20.308 a	-	13.984 a	-	2.360 c	-	-	126.574 d	-
***Anthemis maritima*L.**	27.417 a	34.724 b	23.760 a	43.325 c	12.393 d	93.795 e	-	-	41.468 c	58.814 f
***Cyperus capitatus* Vand.**	-	3.463 ab	-	1.806 a	-	4.647 b	-	-	-	69.560 c
***Ononis variegata*L.**	2.872 a	48.393 b	-	50.274 b	-	22.658 c	-		-	10.294 d
***Medicago marina*L.**	-	34.770 a	0.860 b	6.677 c	-	7.177 c	-	-	-	33.947 a
***Crucianella maritima*L.**	-	-	-	-	-	-	-	-	-	41.335
***Calystegia soldanella*(L.) R. Br.**	0.007 a	-	-	-	-	0.025 a	-	-	-	0.262 b
***Sporobolus pungens*(Schreb.) Kunth**	15.391 a	2.651 b	7.301 c	1.116 d	-	12.090 e	-	0.140 f	23.948 g	5.115 bc
***Silene colorata*Poir.**	0.234 a	1.023 b	0.012 c	0.809 bd	-	0.630 de	-	-	-	0.470 ae
***Pancratium maritimum*L.**	-	2.614 a	-	4.375 b	2.316 a	163.306 c	-	-	22.888 d	105.987 e
***Salsola kali*L.**	0.047 cd	-	0.006 a	-	0.006 a	-	0.084 b	0.063 bc	0.022 d	-
***Chamaesyce peplis* (L.) Prokh.**	0.002 a	-	0.003 a	-	0.003 a	-	-	-	0.023 b	-
Total	**266.646**	**298.493**	**275.680**	**304.995**	**154.180**	**367.922**	**5.954**	**108.150**	**376.218**	**394.378**

total variance. Factor 1 and 2 accounted for 34.80% and 18.53% of the total variance, respectively. The first factor reflected the turnover of the vegetation along the sea-inland vegetation zonation, with higher scores of the factor indicating species closer to the water-edge. Variation in species composition among plots was greater in the longer and less disturbed transect of P (P_2) as underlined by a greater dispersion of the plots in this sub-area along the second ordination axis (**Figure 5**).

4. Discussion

The natural vegetation of the Tyrrhenian coast which includes "The Roman Coast State Nature Reserve" until the years 1970-1980 was characterised by different vegetation bands. In particular, after the aphytoic dune area, the first community on the strandline was characterized by *Ca. maritima*, *E. peplis* and *Salsola kali*, followed by a second community on the foredune with *E. farctus*, *S. pungens*, and *C. capitatus*. The third community which contributed to dune consolidation was characterized by *A. arenaria*, *E. spinosa*, *O. variegata*, *E. maritimum* and *M. marina* and the inner community by *Cr. maritima* and *P. maritimum*, followed by the Mediterranean maquis [9,35].

In stressful environments, species are patchily distributed [36-38], however, spatial species aggregation may also be caused by within-community environmental heterogeneity and preference for common micro-habitats [39]. Our results on the whole show significant variations of species presence and density between Ostia and Marina di Palidoro in response to the different human disturbance. The strong human disturbance at Ostia is the result of the large presence of beach establishments, numerous buildings, the intense use of mechanical means to clean the area and a strong human trampling all year long, which have largely altered the sand dune, and in particular the foredune. In response to these factors, species colonize the dune area, on an average, at 79 m from the water-edge (mean of O_1 and O_2) extending along the gradient toward the inland over a length of 26 m (mean value). PD is 40.8 ± 9.9 plants·m^{-2} (mean of all the considered O plots). In particular, *O. variegata* and *E. farctus* have the highest PD (15.4 ± 1.3 plants·m^{-2} mean value), followed by *S. colorata* and *S. pugens* (4.3 ± 3.9 plants·m^{-2}, mean value), by *Ca. maritima*, *E. spinosa*, *E. maritimum*, *A. arenaria*, *A. maritima*, *C. capitatus*, *M. marina* and *C. soldanella* (lower than 0.5 plants·m^{-2}). *C. soldanella* is a prostrate plant with long rhizomes that survives seawater inundation better than many other species [40] which causes the aerial parts to die but the buried rhizome may survive. This species co-occurs with *E. farctus* in many other foredune areas in Europe [41]. H and TPB vary from 18.3 m to 31.6 m and from 266.7 g·m^{-2} to 305.0 g·m^{-2}, respectively.

The lower human disturbance at P in respect to O, determines the species presence, on an average, at 14.5 m from the water-edge extending along the gradient toward

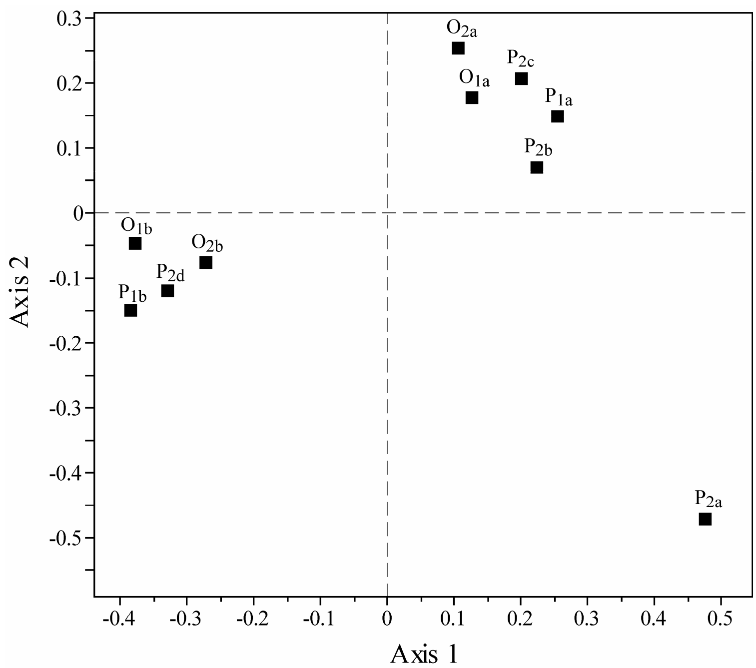

Figure 5. Ordination diagram of the considered plots for Ostia (sub-areas O_1 and O_2) and Marina di Palidoro (sub-areas P_1 and P_2). The variance associated to the first two axes of the principal coordinate analysis is 34.80% and 18.53%, respectively.

the inland for a length of 61 m (mean value) and PD is 21.5 ± 16.1 plants·m^{-2} (mean of all the considered P plots). In particular, *S. pungens*, *E. farctus and O. variegata* have the highest PD (6.0 ± 2.4 plants·m^{-2}, mean value), followed by *C. capitatus* (2.1 ± 4.7 plants·m^{-2}, mean value), by *S. colorata* and *A. maritima* (0.4 ± 0.1 plants·m^{-2}, mean value) and by *E. spinosa*, *E. maritimum*, *M. marina*, *P. maritimum and C. soldanella* (lower than 0.2 plants·m^{-2}). *E. farctus* and *A. arenaria* are rhizomatous species, with this last being the most important sand-fixing species with positive effects on sand stability [18,34,42] and the mycorrhizal symbiosis playing an important role in the growth [43,44].

The results underline the larger species presence along the gradient from the water-edge toward the inland in P compared to O where, on the contrary, plants exclusively colonize the inner areas due to the strong human disturbance which causes the fore-dune to become flat. Moreover, P_2, characterised by a relatively lower disturbance than P_1, has a 72% higher PD and a species distribution over a longer strip from water-edge toward the inland (53 and 73 m in P_1 and P_2, respectively). The study underlines the ability of the considered sand dune species to colonize the inner patch where microclimate and soil conditions are more favourable (by a 56% lower wind action and 12% higher SOM content, mean of the considered O and P plots) than the areas closer to the water-edge. In response to the more favourable conditions, H increases by 62% in the plots further from the water-edge.

5. Conclusion

An increase in human impact in the near future, along with global change, could act on sand dune species changing their tolerance to stress factors. A management plan needs to restore the most damaged dune areas and actively prevent further environmental impacts. This could be accomplished by developing and implementing strategies which reconcile demands for human recreation with conservation that is within the ecological carrying capacity of coastal dunes [45]. Vegetation is an important controlling factor for dune morphology [46]. An efficient conservative management would consist of a temporary protection of already degraded areas [2]. A combination of a large variety of driving forces might suggest an unsurmountable complexity. In fact every dune site has its own history and management policy which should incorporate this [22]. Moreover, the maintenance of coastal areas depends on the maintenance of native species [47]. Our results give information on the biodiversity of the Tyrrhenian coast including a natural protected area. The presence of the most important autoctonous sand dune species (on an average, 15, 15, 15 and 16 autoctonous species grow at O_1, O_2, P_1 and P_2, respectively) can provide information for restoring the perturbed dune areas when preparing management strategies. In particular, *A. arenaria* could have a positive effect on sand dune stabilization by contributing to plant colonization under favourable conditions [48]. It must be emphasized that species diversity and recovery capacity depend mostly on the undisturbed sand deposits in the foredunes by the limitation of human trampling and use of mechanical means and infrastructure development. This could favor sand deposits and consequently the species shift from the inland toward the water-edge, thus maintaining the coastal areas and their ecosystem services.

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