This is the peer-reviewed version of the article accepted for publication in JOURNAL OF COASTAL RESEARCH Volume 95, 34-38. 2020, which has been published in final form at https://doi.org/10.2112/SI95-007.1

Recovery of beach-foredune vegetation after disturbance by storms

Juan B. Gallego-Fernández[†*], José A. Morales-Sánchez[†], M.Luisa Martínez[§], José G. García-Franco[§], and María Zunzunegui

[†] Departamento de Biología Vegetal y Ecología, Universidad de Sevilla, Sevilla, Spain

[§] Instituto de Ecología A.C. Xalapa, Veracruz, Mexico

ABSTRACT

Beaches and foredunes are characterized by being exposed to harsh environmental restrictions mainly due to salt spray, burial by sand and occasional storms. In response to this, plant species from these habitats have adaptations that allow them not only to survive in these environments, but also to recover after the impact of disturbances such as severe storms. In this study, we had the opportunity to study vegetation recovery on the coast of Huelva, Spain, after the impact of a strong winter storm in 2017 which severely affected the vegetation growing on the beach and foredune. Species composition and abundance of vegetation were compared before (2013) and after (2018) the storm hit the coast in 2017. The results show that the effects of the storm were still evident a year later. Native species, mainly perennials, were able to recover almost completely to pre-disturbance levels. In contrast, the invasive species, *Oenothera drummondii*, which was abundant before the storm, disappeared from the beach and its presence in the foredune was greatly reduced. Given the forecasts of sea level rise and the increased frequency and intensity of storms, it is necessary to sustain and reinforce the natural coastal sectors where native plant communities maintain the resilience of coastal ecosystems when impacted to these disturbances.

KEYSWORDS: *Coastal dunes, Gulf of Cadiz, Oenothera drummondii, plant diversity, Spain*.

INTRODUCTION

Coastal dunes are in the transition zones between marine and terrestrial ecosystems. Here, the specialized flora and fauna are adapted to thrive under the harsh environmental conditions (drought, low nutrient availability and burial by sand, among others) (Hesp, 1991; García-Mora *et al*., 1999; Maun, 2009). They can also recover after the impact of recurrent disturbance events such as storms, which under extreme circumstances, can completely eliminate plant cover. Beaches and foredunes are especially vulnerable to the impact of storms (Hesp, 2002; Gornish and Miller, 2010), especially in a climate change and sea-level rise scenario. During severe storms, the beach and foredunes may be overtopped by storm surges as a result of a local sea level rise and strong waves, resulting in intense sediment movement. As this occurs, the roots of plants can become exposed after erosion or, the plants can be completely covered by sand (Snyder and Boss 2002). Frequent and severe storms can certainly alter the structure and composition of the plant communities that develop on the beach and dunes (Snyder and Boss, 2002; Cheplick, 2016).

There are few studies that focus on how the beach and dune vegetation recovers after the damaging effects of hydrometeorological events, such as storms (Gornish and Miller, 2010). Most of them have been carried out on the barrier islands from eastern USA which are frequently disturbed by hurricanes. Here, it was observed that the recovery occurs at a relatively fast rate, within a few months or a few years (Miller *et al*., 2010; Cheplick, 2016). Recovery rates depend on the intensity of the disturbance, the alongshore hydrosedimentary dynamics, the structure of the vegetation, the attributes of the species and the characteristics of the dune landscape at a local and regional levels (García-Mora *et al.*, 1999; Miller *et al.*, 2010; Gallego-Fernández *et al*., 2011; Cheplick, 2016).

On February 12, 2017, a severe storm hit the coast of the province of Huelva (SW Spain) with maintained winds of 52 km / h and 50 cm tidal arises, which coincided with the high tide period. An important overwash occurred along the coast, affecting the beach and foredunes. Given the fact that the vegetation growing on the dunes of this coast had been described in detail previously in 2013 (Gallego-Fernández *et al.*, 2019), a unique opportunity arose to examine how a storm of this nature affected the plant communities and how they recovered a year later.

In the study carried out in 2013, Gallego-Fernández *et al*. (2019) showed that the dunes in this sector along the coast of Huelva have been invaded by *Oenothera drummondii* since 1996. These earlier studies revealed that, upon arrival, this invasive plant (native from the Gulf of Mexico), modified the composition, structure and functioning, of the plant communities, increasing its impact inland from the beach towards the inner dunes. Gallego-Fernández *et al*. (2019) concluded that the harsh environmental conditions of the beach and foredunes reduced the colonization and invasion success by this species, which was similar to the findings for other invasive species (Acosta *et al*., 2008). The study of the effects of storm impact on the population of *O. drummondii* could support the suggested relationship between high environmental stress and a limitation in the invasive success of *O. drummondii*. The objective of the present research was to compare the composition and abundance of the plant community of beach and dunes before (data from Gallego-Fernández *et al*., 2019) and after the above-mentioned storm, and to determine how the plant community recovered a year after. In addition, the effect of storm disturbance on the invasive species, *O. drummondii*, was assessed.

METHODS

Study area

The study took place in a coastal dune system of Huelva (Gulf of Cádiz), Spain (37° 9′ 20″ N, 6° 54′ 40″ W). The climate is Mediterranean with winter rain and summer droughts, a mean annual temperature of 17.8°C and a mean annual rainfall of 467 mm. Tides in the Huelva coast are semidiurnal with a mesotidal range, Mean Spring Tidal Range (MSTR) of 2.82 m (Morales *et al*., 2001). This coast is affected by SW storms. An average of 15 storms per year can affect this system, with mean wave height of 3.80 m and storm surge with exceptionally high waves reaching 6 m (Morales, 1997).

The dunes of the studied site were formed recently, just after the construction of the jetty Juan Carlos I in 1981 (Rodríguez-Ramírez *et al*., 2008). The dune system stretches for 7 km running parallel to the jetty and its width varies between 200–400 m width. This dune system is in a prograding coastal sector with continuous growth towards the sea since the construction of the jetty. Several storms hit this coast between 2013 and 2017, but field observations indicated that the vegetation was not significantly affected. However in February 2017 a strong storm hit the site, resulting in flooding of the beach and foredune overwash; all the vegetation from the beach was removed by the storm surge, and most of the vegetation from the foredune was also eliminated (Figure 1).

Vegetation sampling

In April 2013, a 200 m wide sector, parallel to the shoreline, was stablished to study the dune vegetation. A total of 37 plots (2 x 2 m) were randomly distributed, 13 on the beach and 17 on the foredune. In each plot, relative cover of each species and percentage of bare sand were visually estimated. Further, the longest and shortest diameters of each *O. drummondii* plant were measured to estimate their individual sizes. In April 2018, the same sector was resampled with the same methodology. A total of 44 randomly distributed plots were sampled, 21 on the beach and 19 on the foredune. Each plot was established at 5 m east of the 2013 plots, because in this first sampling all the O. drummondii plants were removed for biomass estimates. The following attributes were recorded for each plant species found in the sampling quadrats: a) relative plant cover (as a visual estimate of percent cover in the plot); b) life form; c) types of propagules, and d) dispersal by sea water.

Figure 1. Foredunes in the Jetty Juan Carlos I coastal dunes before (2013) (left) and after (2017) (right) the site was hit by a strong winter storm in 2017.

Data analysis

One-way ANOVA was used to test whether mean species richness per plot, total plant cover, plant cover of native species, relative abundance of the invasive species (*O. drummondii*) in terms of plant cover, density (number of plants per square meter) and mean size of individuals, were significantly different between 2013 and 2018 in each studied site (beach and foredune). An *Arc-cosine* transformation was applied to plant cover data before performing statistical analyses and *square rooted* transformation was applied to *O. drummondii* density (m^2), plant size, and species richness. Data of *O. drummondii* were excluded from the species richness analyses.

Additionally changes in community structure were visualized through relative importance curves (Gallego-Fernández and Martínez, 2011), which were calculated to assess whether dominance in 2013 communities differed from that of 2018. Relative Importance values (RI) were calculated by adding relative frequency (proportion of plots in each zone where a species occurred) and relative cover (proportional cover per species, relative to total plant cover [all species] per plot). Finally, before plotting the RI curves, species were ranked in decreasing order of importance, based on plant abundance.

RESULTS

Twenty plant species were identified in both zones and years (Table 1). The total number of species recorded in the foredune (20) was twice what we observed on the beach (10). In both areas (beach and foredune) the total number of species was lower in 2018 than in 2013. Most of the beach species were perennial herbaceous and in the foredune, in addition to the previous ones, 10 annual herbaceous species appeared. Two species were woody, one very abundant, *Otanthus maritimus* in both zones, and another very scarce in the foredune, *Artemisia crithmifolia*.

In 2013, 10 species were recorded on the beach; the most abundant were *Polygonum maritimum* and the invasive species *O.drummondii*, followed by *Ammophila arenaria* and *Otanthus maritimus* (Table 1). In 2018, the abundance of all species decreased, except for *O. maritimus* and *A. arenaria*, which increased considerably; *O. drummondii, C. maritima* and *Salsola kali* were not registered in the plots. All species recorded on the beach can disperse their propagules by sea currents, except for *O. drummondii*. This last species, unlike the others, has a limited capacity of seed dispersing by seawater (JBGF personal observation). In 2013, 17 species were registered on the foredune; *A. arenaria* was the dominant species, followed by *O. drummondii* and *Euphorbia paralias*. In 2018, the abundance of practically all the species found in 2013 had decreased. It was noteworthy that the cover of *O. drummondii* decreased to one sixth of what we had observed prior to the storm. Additionally, 5 non-abundant species in 2013 had disappeared by 2018, and 3 new species were also registered with low abundance. The most abundant species in 2013 and 2018 were perennial herbs whose seeds are dispersed by the ocean currents (Table 1). Furthermore, annual species, typical of inland communities (more stable habitats, less exposed to recurrent disturbance events) and not dispersed by the ocean currents were not observed in 2018.

Total plant cover was significantly higher in 2013 than in 2018, both on the beach ($F_{2,28}$ = 4.49, p = 0.020) and on the foredune ($F_{2,33}$ = 5.45, p = 0.009) (Figure 2a). However, we did not find significant differences in plant cover of native vegetation in either zone ($p > 0.05$) (Figure 2b). In contrasts, in both areas species richness decreased significantly between 2013 and 2018 (Beach: $F_{2,28}$ = 4.34, p = 0.023; Foredune: $F_{2,33}$ = 8.40, p = 0.001) (Figure 2c).

In 2013, the invasive species *O. drummondii* was found on the beach with a plant cover of 3.6 ± 4.9 % (Figure 2d) and density of 0.08 ± 0.12 ind./m^2. In 2018, this invasive disappeared from the beach, and largely decreased from the foredune ($F_{2,33}$ = 14.79, p <0.0001 (Figure 2d). Plant density of the invasive species also decreased significantly (2013: 1.03 ± 0.84 ind/m^2, 2018: 0.34 ± 0.61 ind / m^2; $F_{2,33}$ = 12.78, p = 0.001), as well as the mean plant size (2003: 26.3 ± 22.59 dm^2, 2018: 7.18 ± 7.46 dm^2; $F_{2,33}$= 8.86, p = 0.007).

The rank- abundance curves showed a change in the dominant species between both dates and zones (Figure 3). On the beach, *P. maritimum* was dominant in 2013 with highest values compared to the other species, however in 2018 two species, *O. maritimus* and *A. arenaria*, were co-dominant, and *P. maritimum* retreated to a third position. Species with intermediate IR values in 2013, either disappeared in 2018, or reduced their IR. In contrast with the above, in 2013, three species were co-dominant on the foredune, and they were clearly far ahead from the rest. Community structure in 2018 was quite different: no species was clearly dominant and, most importantly, the relative importance value of *O. drummondii* was largely reduced, and thus, it was no longer the dominant species. In turn, *O. maritimus* and *A. arenaria* became dominant.

DISCUSSION

The impact of high-energy storms occurring along the coast of Huelva can be high and result in drastic changes on the beach and foredunes of littoral spits (Rodriguez-Ramirez *et al*., 2003). Specifically, the storm that hit the coast in February 2017 removed all the vegetation from the beach and most of it from the foredune. One year after the storm, the vegetation had largely recovered, both on the beach and the foredunes, although there were differences regarding the vegetation structure and composition before and after the disturbance, in 2013.

Additionally, vegetation recovery varied depending on the habitat (beach and foredunes) as well as the life cycle attributes of the colonizing species (Fahrig *et al*., 1993; Cheplick, 2016). In coincidence with our results, previous studies have shown that storm surges and flooding can largely affect the vegetation from the beach. Occasionally, foredune vegetation can also be affected, especially if the foredunes are fragmented. Nevertheless, plant communities can recover in both, the beach and foredunes after the impact of severe storms (Miller *et al*., 2010; Maun, 2009; Cheplick, 2016).

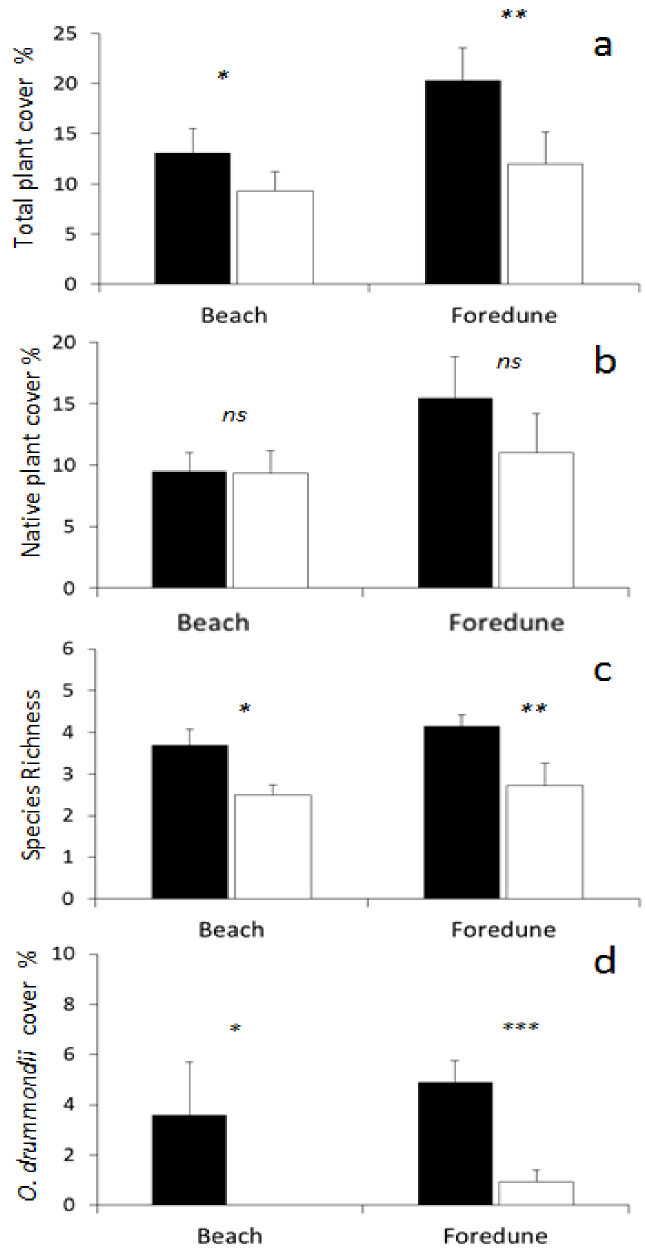

Figure 2. Relative cover of total plants (a), native plants (b) and *Oenothera drummondii* plants (d) (mean ±se) at the beach and foredune in 2013 (black bars) and 2018 (white bars). Species richness (c). Comparisons between dates are indicated (ns=not significant; ** = p <0.01; ** = p < 0.001;*** = p < 0.0001).

The recovery of beach vegetation

Our results show that native perennial species were able to re-colonize the site after the intense storm surges, which coincides with previous studies (Cheplick 2016). Specifically, such effective re-colonization occurred because of the rapid growth of two native perennials: *O. maritimus* and *A. arenaria*, which can grow from rhizomes and broken stems. Both species are very abundant along the coasts of Huelva, and thus, their propagules can be easily dispersed from nearby areas. The remaining perennial species were scarce probably because they were less abundant along the coast of Huelva, and the difficult dispersal of their propagules. Annual species such as *C. maritima* and *Salsola kali* are effective colonizers (Pakeman and Lee, 1991). However, they disappeared after the storm in 2013, while perennials were better able to recover (Maun, 2009).

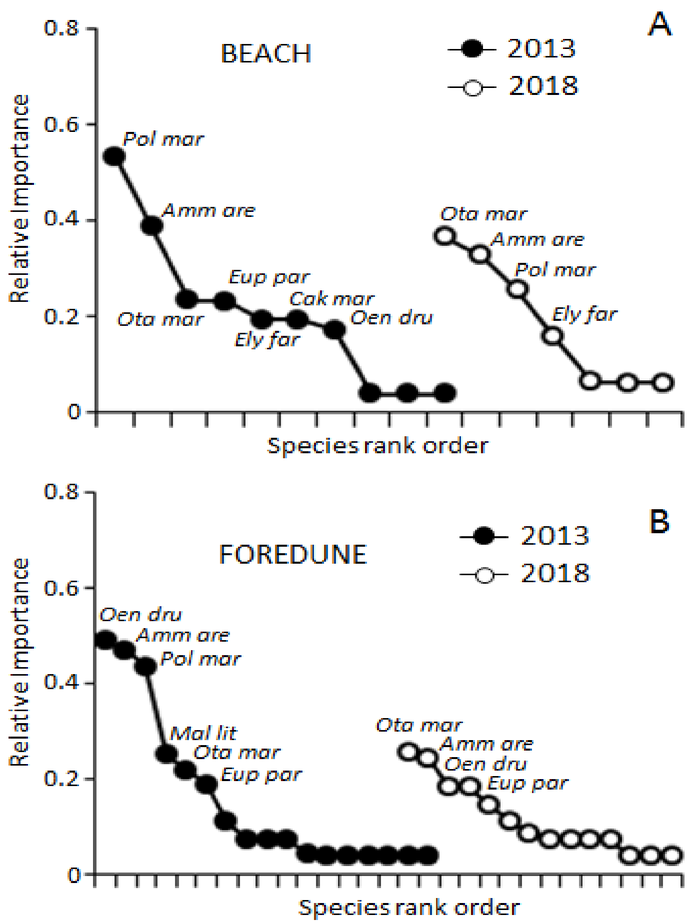

Figure 3. Figure. Rank-abundance curves based on relative cover and frequency of occurrence of species within plots for the beach (A) and foredune (B) habitats in 2013 and 2018.

The recovery of foredune vegetation

Recovery of foredune vegetation mostly occurred through the re-colonization of *A. arenaria*, which is a key-species in European foredunes. The fast recovery of *A. arenaria* probably occurred because many stands of this species survived the storm surge and burial. Nevertheless, plant cover was still 10% lower than that previously observed in 2013. The other perennial species which were relatively scarce in 2013 were also able to re-colonize the disturbed dunes, but their abundances remained scarce. Finally, five annual species, which are not tolerant to burial and salinity (García-Mora *et al*., 1999) disappeared between the two periods observed.

Table 1. Species composition in studied plots of beach and foredune. LF (Life form): AH = annual herb, PH=perennial Herb, BH: biennial Herb, W: woody. PRO (Propagules): S=seeds, R= rizhomes, B= bulbs, PF=plant fragments. Mean cover of species per plot (%) in 2013 and 2018 (highest values in bold).

	LF	PRO	SWD	2013	2018
Beach					
Polygonum maritimum	PH	S	+	**6.67**	0.94
Oenothera drummondii	PH	S	+	**3.6**	
Ammophila arenaria	PH	S, R	+	0.79	**2.79**
Otanthus maritimus	W	S, PF	+	0.69	**4.28**
Euphorbia paralias	PH	S	+	0.5	0.06
Elymus farctus	PH	S, R	+	0.47	0.31
Cakile maritima	AH	S	+	0.19	
Eryngium maritimum	PH	S, PF	+	0.12	0.28
Pancratium maritimum	PH	S, B	+	0.01	0.04
Salsola kali	AH	S	+	0.01	
Bare soil				86.96	91.22
Foredune					
Ammophila arenaria	PH	S, R	+	**9.09**	**6.27**
Oenothera drummondii	PH	S	+	**5.26**	0.8
Euphorbia paralias	PH	S	+	2.09	0.52
Lotus creticus	PH	S		1.54	1.68
Polygonum maritimum	PH	S	+	1.23	0.01
Otanthus maritimus	W	S, PF	+	0.78	0.52
Silene nicaeensis	AH	S		0.52	0.12
Pancratium maritimum	PH	S, B	+	0.48	0.5
Conyza albida	AH	S		0.33	
Malcolmia littorea	BH	S		0.16	0.37
Elymus farctus	PH	S, R	+	0.03	0.01
Pseudorlaya pumila	AH	S		0.03	0.01
Erodium cicutarium	AH	S		0.02	
Reichardia gaditana	AH	S		0.02	
Tolpis umbellata	AH	S		0.02	
Cakile maritima	AH	S	+	0.01	0.01
Euphorbia terracina	AH	S		0.01	
Eryngium maritimum	PH	S, PF	+		0.21
Artemisia crithmifolia	W	S			0.01
Linaria pedunculata	AH	S			0.05
Bare soil				78.38	88.89

Effects on invasive species

The invasive species, *O. drummondii*, was very affected by the storm. Observations after to the storm showed that all the individuals had either disappeared from the beach or were dead owing to salinity and sand burial brought by the storm surge. This supports the conclusions of Gallego-Fernández *et al*. (2019), who stated that the establishment of *O. drummondii* on the beach is limited by local extreme conditions such as salinity and burial. Thus, because seed dispersal of the invasive species *O. drummondii* has seldom been observed to occur through ocean currents (JBGF personal observations), it is possible that recolonization occurred through endozoochory (hares), from surviving individuals growing on inland dunes (Gallego-Fernández *et al*., 2019).

CONCLUSIONS

The results of this study showed that plant communities from the natural sectors of the coasts along the Gulf of Cádiz can recover at a relatively fast rate after the impact of severe storm events. The diversity of native species adapted to such extreme conditions, coupled with the availability of propagules in nearby areas, promoted the rapid recovery. However, this capacity of recovery may change in the near future. As sea-level rises, coastal erosion will increase, and consequently, beaches and dunes will be eliminated and their vegetation will be lost or altered (Feagin *et al* 2005). Similarly, the predictions from the IPCC (2019) suggest that storms will increase in terms of frequency and intensity, increasing even further shoreline erosion. Both factors, together with human impacts on the coast (Pontee, 2013), can also threaten the natural recovery of plant communities after the impact of extreme hydrometeorological disturbances. Given this situation, it is necessary to carry out detailed long-term studies that address the responses of the beach and dune vegetation to severe disturbance events. With this we will be able to identify those species that are better able to respond to disturbances and therefore may be the most suitable for restoration projects (Gornish and Miller, 2013).

ACKNOWLEDGMENTS

We thank the students who helped with the field work and the staff from the Paraje Natural Marismas del Río Piedras y Flecha de El Rompido for the facilities to carry out the field work. The manuscript was written during the sabbatical of JGGF at the Universidad de Sevilla supported by CONACYT, México (CVU 7799). Funding was provided by Ministerio de Economía y Competitividad (MINECO Project CGL2015-65058-R co-funded by FEDER).

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