Sand dune and saltmarsh resilience in the eye of Climate Change

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Introduction

Sand dunes and salt marshes are coastal ecosystems, and their existence is due to the interaction between water and terrestrial systems, and the dynamic process created in this interaction is necessary for the systems to persist (Hanson et al. 2002; Everard et al. 2010). These ecosystems are of high ecological interest being habitat to many species and providers of ecosystem services such as carbon and pollutan sequestration, water purification, recreation or cultural knowledge (Elsey-Quirk et al. 2019). Although, they are natural frontiers that protect our terrestrial land from the effect of sea-level raise and strong sea waves occurring, nowadays they are directly threatened by the sea level rise, river water regime change or water temperature increase due to climate change. According to the latest Article 17 report (2007-2012), for the vast majority of Member States, 70% of coastal habitats were reported as being in an 'unfavourable' conservation status, and it is the same fo the Basque Country (EJ 2016). For example, of the 75% of the sand dunes systems present in Europe a century ago just 45% were in a natural way (Sanjaume and Gracia 2011). Thus, there is an urgent need for these natural ecosystems to be preserved and restore (Zedler and Kercher,2005), in order to be resilient to these new threats.

The aim of this work was to study the regeneration capacity of two coastal ecosystems (resilience), namely a sand dune and a salt marsh, based on plant diversity, as plants are good indicators of site conditions.

Materials and methods

Both study sites are located in the coast of Biscay in two estuaries: the sand dune restoration project in the Butroi estuary in Gorliz, and the salt marsh restoration project in the Barbadun estuary in Muskiz (Figure 1). The coast mean annual temperature is 14.6 ºC and annual precipitation is 1.200 mm.The former proyect had two phases: one started in 2009 where 62.000 m^2 of sand and dune site was reclaimed removing a car-park and 80.000 plants of *Ammophila arenaria*, *Elymus farctus*, *Festuca juncifolia* y *Pancratium maritimum* were planted (Figure 1, right site A), and the other in 2015 where 2.019 m^2 were reclaimed, sand captors were set and some species such as *Ammophila arenaria* were planted (Figure 1, right site B) (Magrama 2016). The A site had two subsites divided by a path to enter the beach (A1 and A2). The saltmarsh restoration started in 2008 where 18 ha were reclaimed 465.000 m soil cleaned and 72.000 plants planted and artificial channals dug for the water to enter the site (Revista electrónica de CLH 2012). Sampling was done in 2016 in the former and in 2018-19 in the latter.

The methodology followed in both projects was quite similar, based on transects and using 2x1 m quadrats as sampled units. In both studies plant species cover was estimated using a semi-quantitative of frequency-abundance that shows the cover following the DAFOR scale in ranges 1 to 5 (Joint Nature Conservation Committee 2004). Shannon and Simpson diversity indices (Magurran 1989) were calculated in the sand dunes following the zoning from the lower zone to the higger zone, further from the sea. The nomenclature followed was that of Flora Europaea (Tutin et al. 1964-1980), except for *Tortula rurales* (Hedw.) Gaertn species.

Figure 1. Restoration sites: sand dune restoration before the car park in 2009 (A) and restaurant in 2015 removal (B) (left) and saltmarsh restoration before the refinery deposits removal (left) and after (right). In the salt marsh the red letters show the recovered site A and the control site C.

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Results and discussion

Results showed that in the older sand dunes 17 sand dune plant species were present while in the 2015 site had just 11 species. The briofite *Tortula rurales*, species related to stabilized dunes was present on one side of the older dunes (A1) while the species *Oenothera biennis*, related to disturbance, was only in the adjacent site (A2). However, three species not present in the older restoration site were present in the younger site: *Aetheorhiza bulbosa*, *Eryngium maritimum* and *Malcomia littorea*, probably due to the closeness to a natural sand dune. The plant species found in the sand dunes in Gorliz were similar to those found in oher sand dune restoration sites of the nearby coast, Laida, from 2002 to 2008 (Gallego-Fernandez et al. 2011). Moreover, in the sand dune restored in 2009 the typical profile in plant diversity was already found (lower zone, middle and upper zone), diversity increasing from the seaside to the inland site and significant differences were found among the zones (Simpson, H= 20.858, p= 0.0001 y Shannon, H= 20.79, p= 0.0001 for A1; Simpson, H= 8.45, p= 0.004 and Shannon, H= 8.44, p= 0.004 for A2) (Figure 2, left). This profile was not significantly found in the younger dune (Figure 2, right). Nevertheless, the floristic composition in the lower part was very similar in the two restoration sites even if in the younger site some were missing due to the short restoration time. The conditons on this lower zone, namely sea innundation, wind erosion, substrate movement, are of high stress (Chapman 1976) not allowing the presence of many plant species but as sand dune profile developes (organic matter accumulation, humidity etc.) the diversity increases (Margalef 1974).

On the other hand, in the saltmarsh restoration site 13 plant species were present, *Sarcocornia fruticosa* and *Hamilione portulacoides* the most abundant ones, typical of the lower part of the saltmarsh, while there were also some typical of the higher part such as *Sarcocornia perennis*. The number of species was not far from those found in a similar size saltmarsh in the Butroi estuary, nevertheless, far from that found in a natural but bigger saltmarsh of Urdaibai (36 species, Oka estuary). It is worth mentioning, that after 35 years of regeneration just a bigger size salt marshes in the Txingudi bay had 16 species (Onaindia et al. 2001). Nevertheless, lower number of plant species found in the natural site but the plant cover was higher. This site was more stable and the recovering site was still more affected by the tide and had a lover profile than the natural site. Plant distribution in the recovering site was similar to that found in the natural site: *S. ramosissima, Aster tripolium* eta *Puccinellia marítima* in the lower site of the salt marsh (Benito et al. 1989), and *Sarcocornia fruticosa*, *Limonium vulgare* or *I.crithmoides* in the higher part of the salt marsh. In general, plants were distributed in relation to geomorphology (data not shown) as in other salt marshes (Onaindia et al. 2001; Chaieb et al. 2018).

Table 1. Plant species abundance based on the DAFOR methodology in the studied sand dunes (A1 and A2 where the car-park was removed in 2009 and B where the restaurant was removed in 2015) and in the saltmarsh (A restoring site since 2008 and C natural site). (1=Rare, 2= Occasional, 3=Frequent, 4=Abundant y 5=Dominant).

Species in the sand dune restoring sites	A1	A2	B
Aetheorhiza bulbosa subsp. *bulbosa* (L.) Cass.	-	-	1
Anthyllis vulneraria subsp. *iberica* (W. Becker) Jalas ex	2	4	-
Ammophila arenaria subsp. *australis* (L.)	5	5	4
Cakile marítima Scop	-	-	1
Calystegia soldanella (L.) R. Br.	3	2	1
Carex arenaria L.	2	1	2
Cistus salvifolius L.	1	1	-
Conyza sumatrensis (Retz. E. Walker)	1	1	-
Elymus farctus (Viv.) Runemark	1	1	1
Eryngium maritimum L.	-	-	1
Euphorbia paralias L.	1	1	2
Festuca juncifolia St. –Amans	1	2	-
Herniaria ciliolata subsp. *robusta* Chaudhri	1	1	-
Leontodon taraxacoides (Vill.) Mérat subsp. *taraxacoides*	1	-	-
Lotus corniculatus L.	1	1	-
Malcomia littorea (L.) R. Br.	-	-	1
Medicago littoralis Rohde ex Loisel	2	2	1
Oenothera biennis L.	1	2	1
Pancratium maritimum L.	1	-	-
Sonchus sp.	1	1	-
Tortula rurales (Hedw.) Gaertn	1	-	-

Species in the salt marsh site	A	C
Ammophila arenaria (L.)	-	-
Aster tripolium (L.)	3	-
Festuca rubra L.	2	-
Halimione *portulacoides* (L.) Aellen	4	4
Inula crithmoides (L.) Dumort	2	5
Limonium vulgare Mill.	2	2
Limonium ovalifolium (Poir.) Kuntze	1	-
Plantago maritima L.	1	1
Puccinellia maritima (Jacq.) Parl.	2	-
Salicornia ramosissima J. Woods	5	4
Sarcocornia fruticosa (L.) A.J.Scott	4	4
Sarcocornia perennis (Mill.) A.J.Scott	2	-
Suaeda maritima (L.)	2	-
Stenotaphrum secundatum (Walt.) Kuntze	-	-
Triglochin maritima L.	2	-
Zostera noltii Hornemann.	2	-

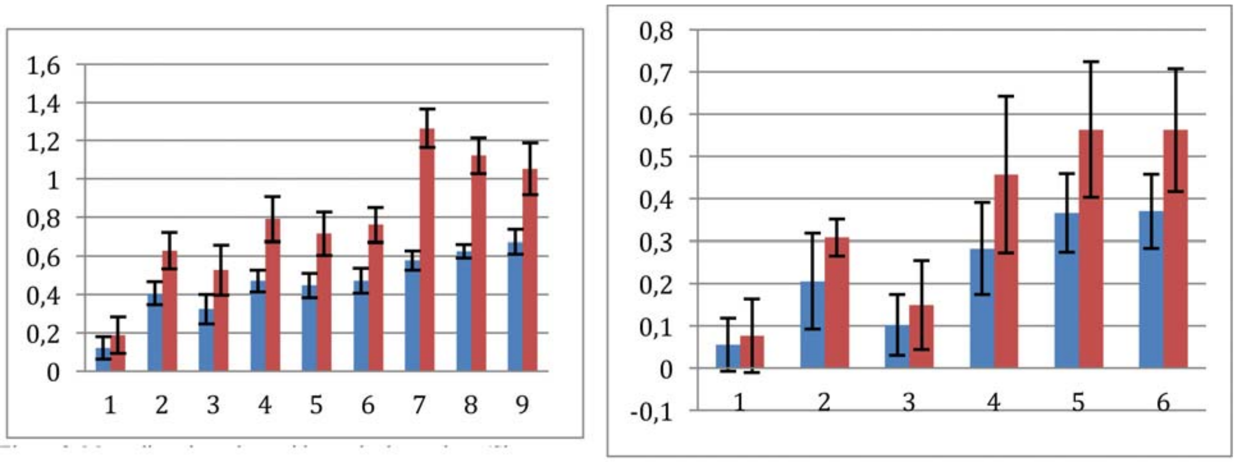

Figure 2. Mean diversity values with standard error bars (Shannon diversity index in red and Simpson in blue) for the sand dune restoration sites: the 2009 restoration site graph on the left (only for site A1) and the 2015 restoration site on the right. Numbers on the X axis are the transects parallel to the beach followed in the sampling: 1-2-3 are the lower zone, 4-5-6 the middle zone and 7-8-9 the upper zone of the dune.

Conclusions

In conclusion, both sites have shown a good recovery trend in species numbers (resilience), even if still far from maturation, however, the sites are restoring the habitat conditions for the typical species. In 7 years the sand dunes have been able to form the typical dune profile in relation to plant species and soil conditions, while just a year is showing the initial formation and suggest the importance of nearby propagule source for a rapid recovery. Moreover, the 10 year restoration process of the saltmarsh shows the presence of a high number of halophyte species, even if not as many as in other more mature saltmarshes. The dynamic nature of these ecosystems favours the recovery process of them, so as also recovering their natural function of protection of the land and resilience from the expected effects of climate change on sea strength and level by 2050.

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