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The Impact of Breeding Yellow-Legged Gulls on Vegetation Cover and Plant Composition of Grey Dune Habitats

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Abstract: The establishment of large populations of yellow-legged gull *Larus michahellis* in coastal and urban areas can lead to strong changes in vegetation cover and composition through creating physical disturbance in the vegetation and impacting the soil quality through defecation. In this study, we evaluated the effects of breeding yellow-legged gull populations on tall and short vegetation cover and plant species composition in old (occupied for 13 years) and new (occupied for 3 years) colony sites in grey dunes of the Algarve, southern Portugal. In each site, sampling plots were used to measure the percentage of vegetation cover in areas with and without breeding gulls. In the old colony site, the cover by tall vegetation was substantially reduced and the cover by short vegetation substantially increased in the areas where gulls are breeding in comparison with the adjacent areas. In the new colony sites, there were only minor differences. The increase in cover of short vegetation in the breeding area of the old colony site was mostly by nitrophilous species (*Paronychia argentea* and *Malcolmia littorea*) and should be explained by the decrease in vegetation cover of tall plant species and by feces deposition. Tall and slow-growing species *Suaeda maritima* and *Helichrysum italicum* covers were negatively affected. Our results showed that yellow-legged gulls affected vegetation cover and composition of grey dunes after 3 years of consecutive breeding, and this should be considered in the management of these habitats where breeding yellow-legged gulls are increasing.

Keywords: colonial seabird; dune vegetation; *Larus michahellis*; microhabitat preferences; nest vegetation; nitrophilous species; Ria Formosa; southern Portugal

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1. Introduction

The increase in human population, consequent growing urbanisation and anthropogenic pressures on ecosystems have led to a progressive reduction and fragmentation of natural habitats. Such impacts translated into a decrease in species richness and diversity, changes in the interactions between urban and adjacent rural populations and created new novel biotic interactions between wildlife and humans [1–4]. The strong population increase in opportunistic wildlife species sometimes potentiates negative interactions and conflicts with humans and impacts natural habitats and native vulnerable species adjacent to urban areas [4–6]. These are particularly evident in generalist species with higher phenotypic and behavioural plasticity such as gulls *Larus* sp. [7,8].

Gulls *Larus* spp. are gregarious larids which live in large colonies in occasions with other sympatric seabird species, and their populations have increased enormously in the past decades, especially the yellow-legged gull *Larus michahellis*. In southern Europe, with around 5000 islands and islets, these species have been increasing exponentially since the 1980s, mainly on small coastal islands close to the mainland, such as Marseille Islands in France, the Balearic archipelago in Spain and Berlenga Island in Portugal [9–11]. Such demographic explosion of yellow-legged gull populations throughout Europe is linked to a consequent increase in negative interactions with both humans and wildlife. The first one involves noise and pollution in cities, contamination of water sources by the transmission of pathogens and parasites, such as *Salmonella* sp., and aggressive behaviour towards humans during the gulls' reproductive period [2,4,9,12]. The second involves competition for food, habitat and breeding sites with other coastal seabirds, ruderalisation of the vegetation and changes in soil nutrients [12–18].

Gulls can impact soil properties by causing eutrophication and ruderalisation of the surrounding vegetation [15], and changing chemically their composition [19,20]. Changes in the flora species have been associated with the deposition of ammonia and nitrate through defecation, thus promoting the appearance of nitrophilous species, and threatening native plant species such as *Stachys brachyclada* [18,21]. The transport and deposition of metals, such as cadmium (Cd) or lead (Pb), from garbage dumps to the breeding grounds, and even the transport of excessive salt adhered to feathers, may change the properties of soils in gulls' breeding grounds [16,18,19,22,23].

Most studies describing impacts of growing seabird populations on vegetation suggest that their disturbance of vegetation and the increase in soil nutrients by droppings contribute to the increase in ruderal and fast-growing annual and bi-annual plant species, and to the decrease in plant species with long life cycles [15,16,24,25]. For instance, Baumberger et al. [15] examined the vegetation changes in small Mediterranean Islands impacted by the expansion of yellow-legged gulls and showed that areas with a higher density of breeding gulls had more ruderal species and less stress-tolerant species. Moreover, de la Peña-Lastra et al. [16] examined soil chemistry and plant composition in relation to the density of breeding yellow-legged gulls in white and grey dune habitats in Galicia, Spain. The authors showed that soil areas with a higher breeding density were more acidic and had a higher content of nitrogen (N) and phosphorous (P), as well as the presence of ruderal and alien plant species (e.g., *Urtica membranacea* and *Parietaria judaica*).

More data are needed on the effects of breeding gulls on vegetation because plant species cover and composition are site-specific. Comparing vegetation cover between areas with and without breeding gulls is important, though previous studies mostly compared areas with different gull densities or resampled the same area over time. This will be key to address the impact of gulls on the vegetation of their colony sites. This study evaluated the extent to which breeding yellow-legged gulls impact the vegetation cover and plant composition of grey dune habitats of barrier-islands of Ria Formosa (Algarve, southern Portugal). This ecosystem contains areas of major conservation importance, classified as sites of community importance (SCI) under the habitat's directive of the European Union, which protects habitats such as grey dunes [26]. We compared the cover of short and tall live vegetation and the cover of specific plant species in areas where gulls breed and adjacent areas where they do not breed. We specifically made comparisons between one site where yellow-legged gulls have been breeding annually in the past 13 years, and two sites where yellow-legged gulls are breeding only in the past 3 years. Overall, we expect the impact of gulls to be stronger in the older breeding site, characterised by low overall vegetation cover, particularly of tall vegetation, but a relatively higher cover of short, ruderal and opportunistic plant species.

2. Materials and Methods

2.1. Study Area

The study was carried out on two sand-dune barrier islands of the Ria Formosa Natural Park, Algarve Portugal (Figure 1): Deserta or Barreta Island (36°57′56.61′′ N, 7°52′21.4752′′ W), and Culatra Island (36°59′20′′ N, 7° 50′25′′ W). These two islands are included in the Ria Formosa lagoon system, which is named as a wetland of international importance under the Ramsar Convention [27]. The climate is wet from October to April, and dry and hot from May to September. According to the European Habitats Directive, the sand-dune barrier islands include the 2110 Embryonic Shifting Dunes, the 2120 Shifting Dunes (also known as white dunes) and the 2130 Fixed Coastal Dunes (also known as grey dunes). Vegetation sampling was carried out in one colony site occupied by breeding gulls for the past 13 years (old colony site, East Deserta Island), and in two colony sites occupied only during the last 3 years (recent colony sites, West Deserta Island and Culatra Island) (Figure 1), all situated in grey dune areas. The number of breeding pairs is higher at East Deserta Island, varying between 400 and 1600 breeding pairs since the colony was established in 2010. Number of breeding pairs at Culatra and West Deserta Islands has varied between 50 and 100. The breeding season lasts from Abril to July, and previous studies showed that yellow-legged gulls from East Deserta feed mostly on fish from fishery discards, and occasionally on smaller proportions of marine invertebrates and refuse [28,29].

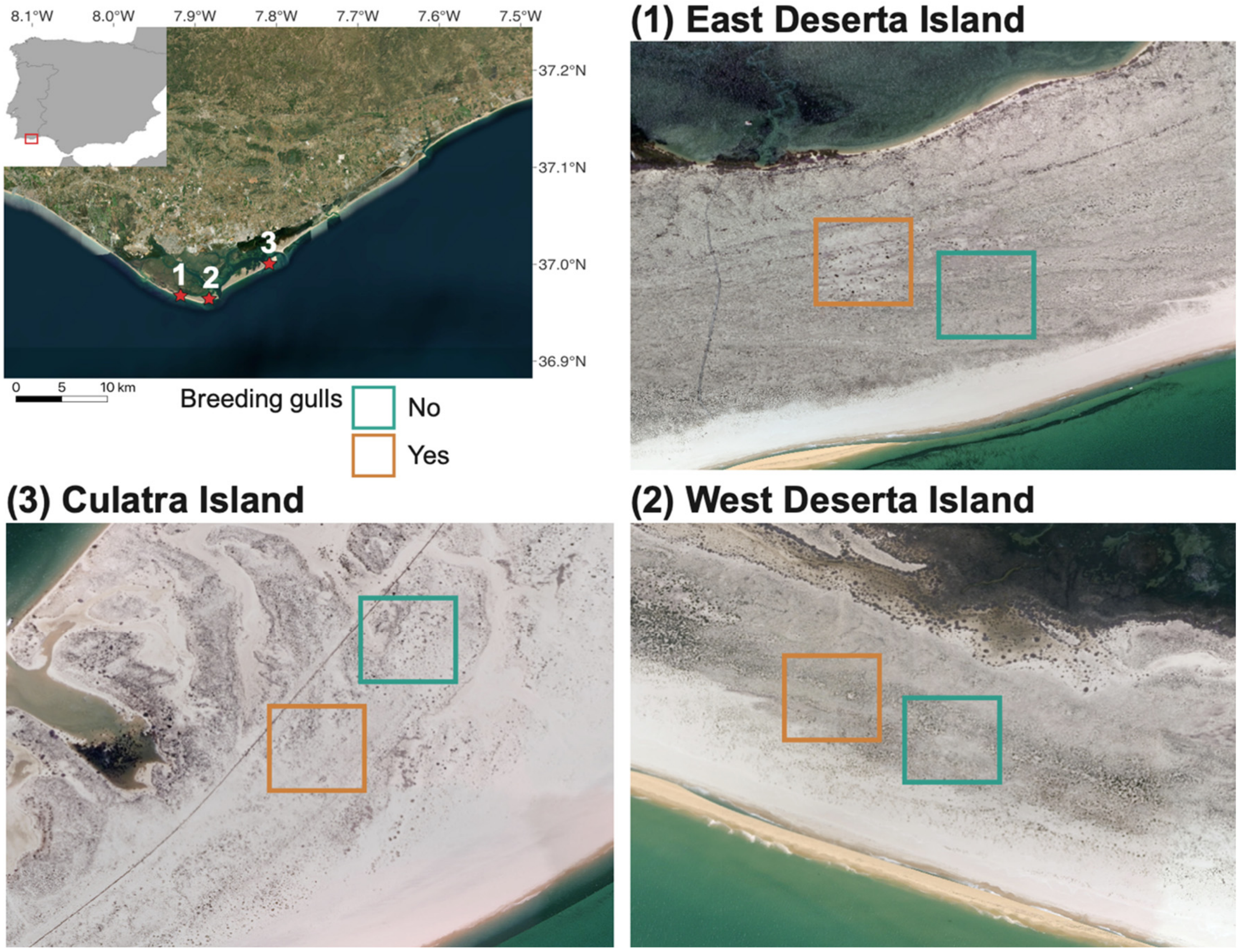

Figure 1. Map showing the location of old (occupied for 13 years; East Deserta Island) and new (occupied for 3 years; West Deserta Island and Culatra Island) yellow-legged gulls *Larus michahellis* colony sites in grey dunes of the Algarve, Southern Portugal. For each study site, we overlaid the vegetation cover (images taken from Google Earth) and identified the areas with (orange) and without breeding gulls (green).

2.2. *Vegetation Cover and Plant Species Composition*

Fifty 5 m^2 plots were established in East Deserta Island (old colony) inside (N = 25) and outside (N = 25) the yellow-legged gulls' breeding area to assess the percentage cover of short (<5 cm) and tall (>5 cm) live vegetation. Vegetation cover was quantified by placing a 1 m^2 quadrat in each one of the four corners of each 5 m^2 plot. Three seasonal sampling periods were established in 2021–2022; summer (June 2021), autumn (September 2021) and spring (April 2022). A similar approach was used at West Deserta Island and Culatra Island (recent colony sites), where forty 5 m^2 plots were established inside (N = 20) and outside (N = 20) the yellow-legged gulls' breeding grounds, and vegetation cover was measured in spring (April 2022). During spring 2022, it was also assessed the percentage cover of each native and alien plant species in all sites.

2.3. Statistical Analysis

Prior to any statistical analysis, all data were tested for normality (Shapiro–Wilk test) and homogeneity of variances (Levene's test). As data did not conform to the previous assumptions, we used a non-parametric Mann–Whitney U Test (test) to compare: (1) The median percentage of short and tall live vegetation cover in areas with and without breeding gulls among seasons (i.e., spring, summer and autumn) at the colony-site of East Deserta Island; (2) the median percentage of short and tall live vegetation cover in areas with and without breeding gulls among colony sites (i.e., East Deserta Island, where gulls have been breeding for the past 13 years; West Deserta Island and Culatra Island, where gulls have been breeding for the past 3 years), during spring; and (3) the median percentage cover of plant species in areas with and without breeding gulls among colony sites (i.e., East Deserta Island, West Deserta Island and Culatra Island). Moreover, we estimated the average effect sizes and their 95% confidence intervals (CI) of each comparison using the effect size R package [30]. We considered effect sizes of 0.2–0.5 as low, 0.5–0.8 as medium and >0.8 as high.

A hierarchical cluster analysis (cluster R package [31]) following the Ward's agglomerative method with Euclidean distances was used to the plant species composition data. Indicator species were also identified for each colony-site/area with and without breeding gulls using the indicator species analysis (ISA) method implemented in the indicspecies R package [32]. All statistical analyses were carried out in R v.4.2.2 [33]. All data are presented as mean $\pm$ SD (standard deviation). Differences were considered statistically significant at p-value ≤ 0.05.

3. Results

3.1. Vegetation Cover in Old and New Colony Sites

The vegetation cover of tall plants in the old colony site at East Deserta Island was significantly lower in the area with breeding yellow-legged gulls than in the adjacent area without breeding gulls for all seasons (Table 1, Figure 2). During spring, the cover of tall vegetation was nearly five times lower in areas with breeding gulls than in areas without breeding gulls. This difference was reduced in summer, presumably because vegetation grew quickly from spring to early summer, but returned to approximately the same values in autumn (Table 1). The opposite occurred for short vegetation, i.e., their cover was significantly lower in the area with breeding yellow-legged gulls than in the adjacent area without breeding gulls (except for autumn).

In relation to the two new colony sites (i.e., West Deserta and Culatra Islands), the only significant difference that was registered was for short vegetation on Culatra Island, which had low power ability (effect size = 0.05; 95% CI = 0.01–0.39), but was significantly lower (p-value = 0.042) in the area with breeding yellow-legged gulls when compared to the area without breeding gulls (Figure 3).

Table 1. Comparison between short (<5 cm) and tall (>5 cm) percentage vegetation cover between areas with and without breeding yellow-legged gulls *Larus michahellis* for: (1) Three different seasons in 2021–2022 for the old colony (where yellow-legged gulls have been breeding for the past 13 years) and; (2) during spring 2022 for the new colonies (where yellow-legged gulls have been breeding for the past 3 years only). Percentages of vegetation cover are mean ± standard deviation (SD), the Mann–Whitney U-test comparing medians between areas with and without breeding gulls (see methods for detailed explanation of evaluation of vegetation cover) and effect size plus 95% confidence intervals (CI). Effect sizes of 0.2–0.5 is low, 0.5–0.8 is medium, and >0.8 is high. Differences were statistically significant when p-value ≤ 0.05.

			Presence of Breeding Gulls		**Mann–Whitney U Test**			**Effect Size**	
		Vegetation Cover	**Yes**	**No**	***Z*-Value**	***p*-Value**	**Effect**	**Index**	**CI 95%**
Season	Spring	Tall	4.3 ± 4.2	18.9 ± 7.5	5.61	<0.001	Yes < No	0.795	0.70–0.85
		Short	31.6 ± 13.0	13.0 ± 5.0	5.35	<0.001	Yes > No	0.758	0.63–0.83
	Summer	Tall	31.1 ± 9.7	37.0 ± 9.8	2.08	0.037	Yes < No	0.295	0.04–0.53
		Short	11.4 ± 3.4	6.8 ± 2.8	4.25	<0.001	Yes > No	0.603	0.40–0.78
	Autumn	Tall	3.5 ± 5.5	22.9 ± 9.2	5.66	<0.001	Yes < No	0.802	0.72–0.86
		Short	16.1 ± 5.9	14.1 ± 4.8	1.08	0.281		0.154	0.01–0.44
Site	East Deserta Island	Tall	4.3 ± 4.2	18.9 ± 7.5	5.61	<0.001	Yes < No	0.795	0.70–0.85
		Short	31.6 ± 13.0	13.0 ± 5.0	5.35	<0.001	Yes > No	0.758	0.64–0.83
	West Deserta Island	Tall	26.9 ± 19.0	31.0 ± 11.7	1.22	0.224		0.195	0.01–0.49
		Short	17.1 ± 10.4	15.0 ± 6.2	0.30	0.766		0.050	0.01–0.41
	Culatra Island	Tall	31.8 ± 10.6	32.7 ± 10.3	0.16	0.871		0.195	0.02–0.50
		Short	15.3 ± 9.4	21.9 ± 10.5	2.03	0.042	Yes < No	0.050	0.01–0.39
Species	East Deserta Island	*Paronychia argentea*	21.4 ± 12.7	8.1 ± 4.9	3.78	<0.001	Yes > No	0.537	0.29–0.73
		Malcolmia littorea	4.9 ± 5.4	2.1 ± 1.7	2.38	0.017	Yes > No	0.338	0.08–0.56
		Helichrysum italicum	0.3 ± 1.0	0.2 ± 0.7	0.84	0.399		0.122	0.01–0.36
		Thymus carnosus	0.4 ± 1.2	7.6 ± 8.4	5.21	<0.001	Yes < No	0.738	0.56–0.88
		Suaeda maritima	1.3 ± 3.4	2.5 ± 4.3	1.02	0.309		0.146	0.01–0.41
	West Deserta Island	*Paronychia argentea*	4.9 ± 8.5	2.1 ± 3.4	0.11	0.913		0.020	0.01–0.35
		Malcolmia littorea	3.9 ± 5.0	0.6 ± 0.9	2.94	0.001	Yes > No	0.467	0.19–0.70
		Helichrysum italicum	3.5 ± 5.8	16.5 ± 8.7	4.06	<0.001	Yes < No	0.644	0.42–0.82

Table 1. *Cont.*

		Presence of Breeding Gulls		Mann–Whitney U Test			Effect Size	
	Vegetation Cover	**Yes**	**No**	**Z-Value**	**p-Value**	**Effect**	**Index**	**CI 95%**
	Thymus carnosus	0.1 ± 0.3	2.5 ± 4.4	2.95	0.003	Yes < No	0.470	0.22–0.66
	Suaeda maritima	12.2 ± 13.7	4.4 ± 5.2	1.99	0.047	Yes > No	0.317	0.03–0.56
Culatra Island	*Paronychia argentea*	5.0 ± 7.4	8.7 ± 12.7	0.24	0.810		0.040	0.01–0.38
	Malcolmia littorea	3.7 ± 5.0	2.1 ± 2.2	0.85	0.393		0.137	0.01–0.45
	Helichrysum italicum	13.5 ± 9.7	7.3. ± 8.7	2.22	0.026	Yes > No	0.354	0.05–0.61
	Thymus carnosus	0.5 ± 1.5	5.8 ± 6.1	3.61	<0.001	Yes < No	0.573	0.33–0.77
	Suaeda maritima	1.8 ± 3.0	0.9 ± 2.1	1.30	0.193		0.208	0.01–0.52

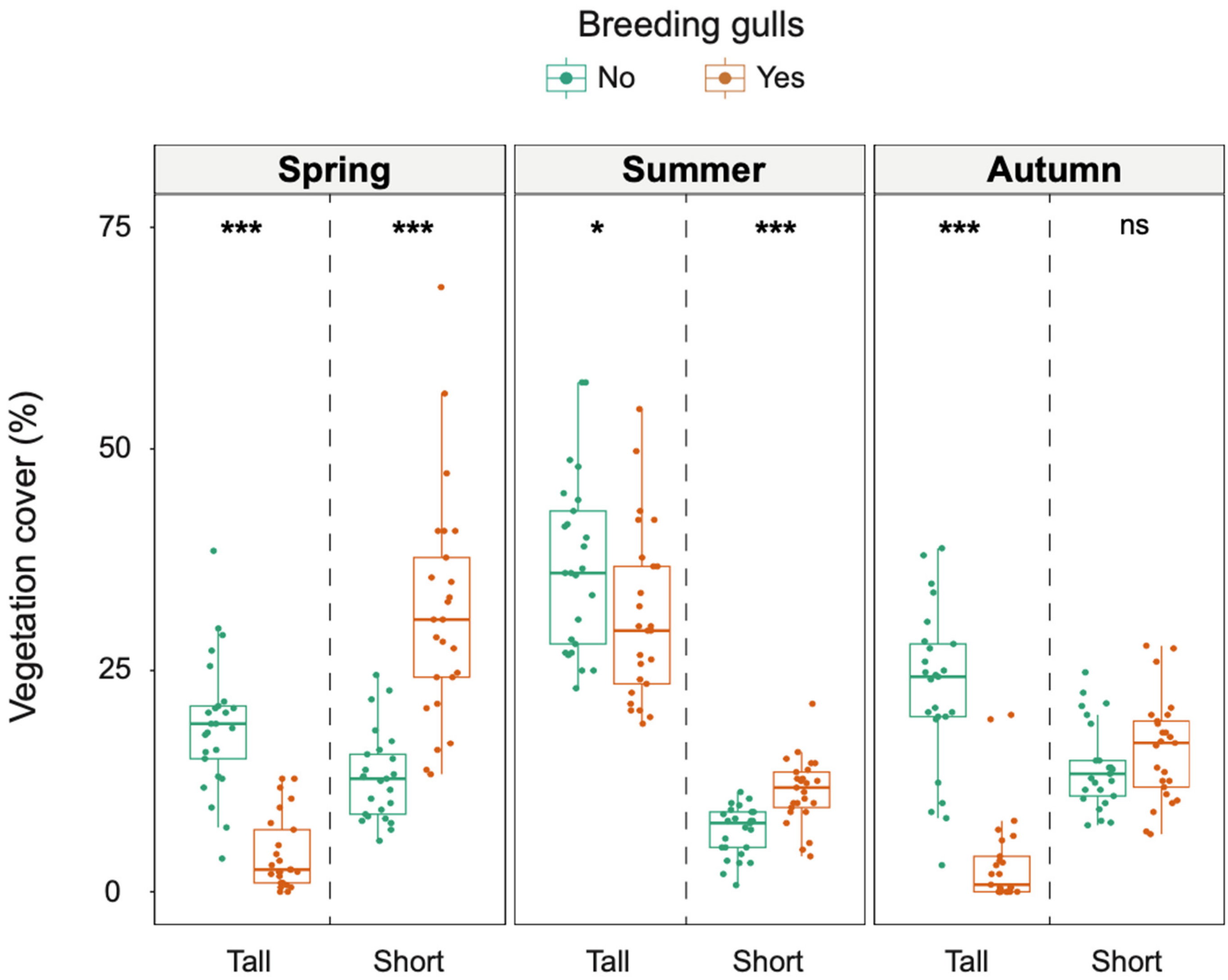

Figure 2. Jitterplots (median, 25–75% percentile range, 1.5 * inter-quantile range) of the percentage cover of short (<5 cm) and tall (>5 cm) live vegetation among seasons (spring—April 2022; summer—June 2021; and autumn—September 2021) in areas with and without breeding yellow-legged gulls *Larus michahellis* at East Deserta Island (i.e., where gulls have been breeding for the past 13 years). ns: non-significant; *: p-value $\leq$ 0.05; ***: p-value $\leq$ 0.001.

3.2. Cover of Plant Species in Old and New Colony Sites

Nineteen plant species were registered in the sampling quadrats during the spring of 2022. In the old colony site, the area with breeding yellow-legged gulls had two more species compared to the area without breeding gulls, and two of these additional species, *Medicago littoralis* and *Plantago coronopus*, are opportunistic and ruderal species (Table 2). In the new colony sites, the number of plant species was slightly lower in the area with breeding yellow-legged gulls than in the area without gulls (15 vs. 17 species for Culatra Island and 7 vs. 9 species for West Deserta Island, respectively; Table 2).

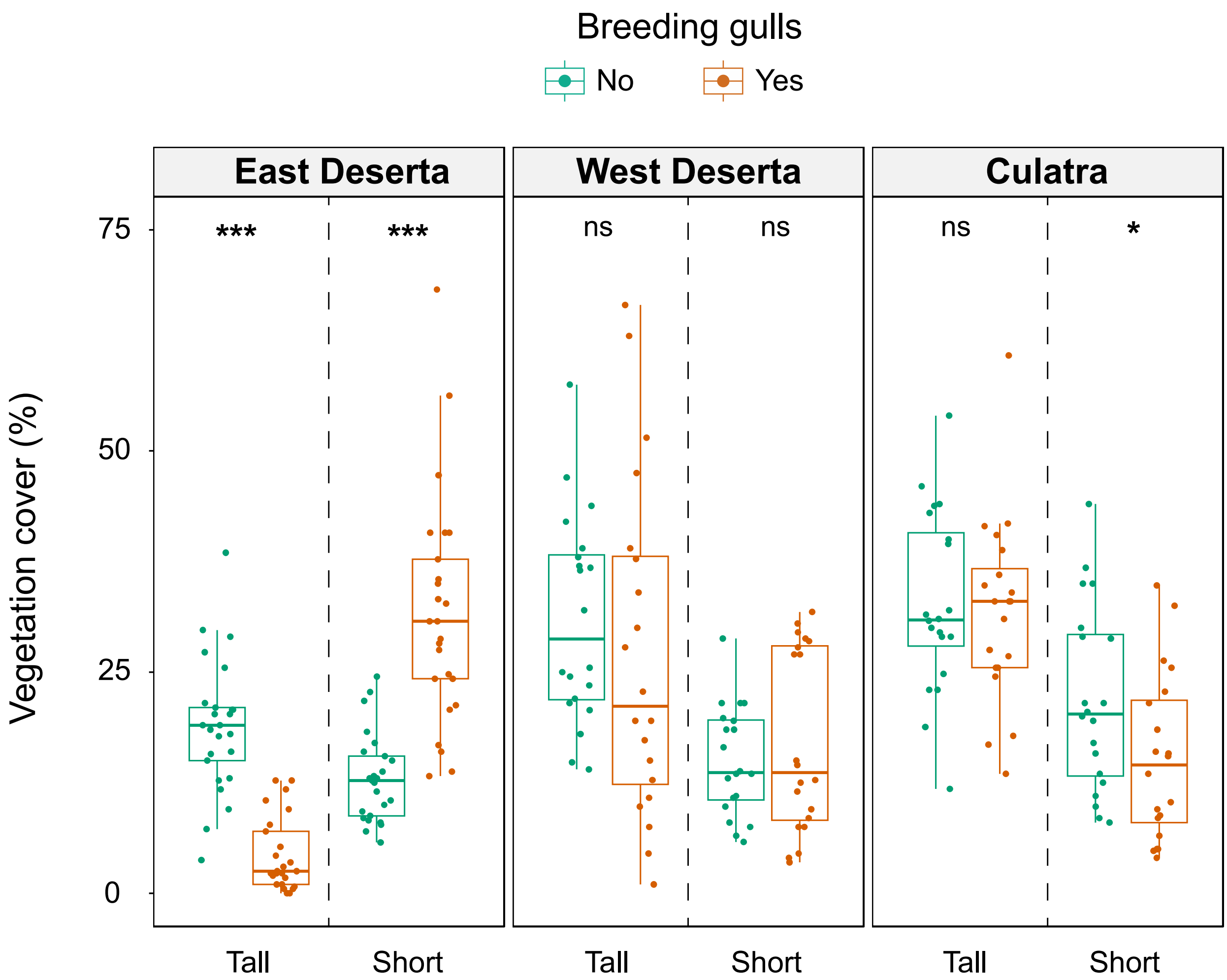

Figure 3. Jitterplots (median, 25–75% percentile range, 1.5 * inter-quantile range) of the percentage cover of short (<5 cm) and tall (>5 cm) spring (April 2022) live vegetation in areas with and without breeding yellow-legged gulls *Larus michahellis* among colony sites (East Deserta Island, where gulls have been breeding for the past 13 years; West Deserta Island and Culatra Island, where gulls have been breeding for the past 3 years). Median, 25–75% percentile range, 1.5 * inter-quantile range. ns: non-significant; *: p-value ≤ 0.05; ***: p-value ≤ 0.001.

The percentage cover of most plant species in each colony site was higher for the area without breeding gulls (Table 2), but only the five dominant native species that coexisted in both areas, with and without gulls, in each colony site were used for statistical analysis (i.e., *Helichrysum italicum*, *Malcolmia littorea*, *Paronychia argentea*, *Suaeda maritima*, and *Thymus carnosus*). In the old colony site, the most dominant species that were found in areas with breeding gulls were two undergrowth species, *M. littorea* and *P. argentea* (Table 2), which had a significantly higher percentage cover in areas with breeding gulls than in areas without breeding gulls. A similar pattern occurred for *M. littorea* on Culatra Island (Figure 4. While in the areas with breeding gulls *P. argentea* was mostly found at East Deserta Island (ISA: 0.51, p-value < 0.001, Figure 5, *M. littorea* was present in both West and East Deserta Island (ISA: 0.29, p-value = 0.02, Figure 5.

Table 2. List of species found in each colony site and the percentage of vegetation cover measured on the areas with and without breeding yellow-legged gulls *Larus michahellis*. The most abundant plant species found in all the three colony sites, and which were further used for the statistical analysis are shown **in bold**. Percentage of vegetation cover are mean ± standard deviation (SD).

Species	East Deserta Island		West Deserta Island		Culatra Island	
	Presence of Breeding Gulls		Presence of Breeding Gulls		Presence of Breeding Gulls	
	Yes	No	Yes	No	Yes	No
Anthemis maritima	-	-	-	-	0.3 ± 1.2	0.5 ± 2.2
Artemisia campestris	0.4 ± 2.0	-	-	-	0.5 ± 1.9	0.4 ± 1.5
Cistanche phelypaea	-	-	-	-	-	0.04 ± 0.2
Crucianella maritima	-	0.1 ± 0.4	0.3 ± 1.1	2.6 ± 3.3	3.7 ± 4.6	1.9 ± 3.3
Erodium sp.	-	-	4.3 ± 5.9	0.1 ± 0.3	0.7 ± 2.9	0.4 ± 1.1
Helichrysum italicum	0.3 ± 1.0	0.2 ± 0.7	3.5 ± 5.6	16.2 ± 8.5	13.5 ± 9.5	7.3 ± 8.4
Limoniastrum monopetalum	-	-	-	-	1.8 ± 7.0	-
Lotus creticus	-	0.8 ± 1.3	3.4 ± 3.8	4.1 ± 5.1	4.6 ± 6.3	14.6 ± 14.9
Lotus subbiflorus	-	-	2.2 ± 5.5	3.8 ± 7.03	0.9 ± 1.9	-
Malcolmia littorea	4.9 ± 5.3	2.1 ± 1.7	3.9 ± 4.9	0.6 ± 0.9	3.8 ± 4.9	2.1 ± 2.2
Medicago littoralis	-	-	0.1 ± 0.4	-	-	0.9 ± 1.7
Pancratium maritimum	-	-	5.3 ± 8.3	5.0 ± 7.1	1.2 ± 1.8	0.5 ± 1.3
Paronychia argentea	21.4 ± 12.5	8.1 ± 4.8	4.9 ± 8.3	2.1 ± 3.3	5.0 ± 7.2	8.4 ± 12.3
Plantago coronopus	0.6 ± 2.2	-	0.3 ± 0.7	-	3.3 ± 4.0	8.6 ± 9.7
Reichardia gaditana	-	1.0 ± 3.0	0.9 ± 1.5	1.5 ± 1.4	0.8 ± 1.0	1.8 ± 3.1
Salicornia europaea	-	-	-	-	-	0.2 ± 1.1
Senecio gallicus	-	-	0.3 ± 0.4	-	-	-
Seseli tortuosum	-	5.6 ± 6.0	-	0.3 ± 0.8	-	1.3 ± 3.0
Suaeda maritima	1.3 ± 3.3	2.5 ± 4.2	12.2 ± 13.4	4.4 ± 5.1	1.8 ± 2.9	0.9 ± 2.1
Thymus carnosus	0.4 ± 1.1	7.6 ± 8.2	0.1 ± 0.3	2.5 ± 4.3	0.5 ± 1.5	5.8 ± 6.0

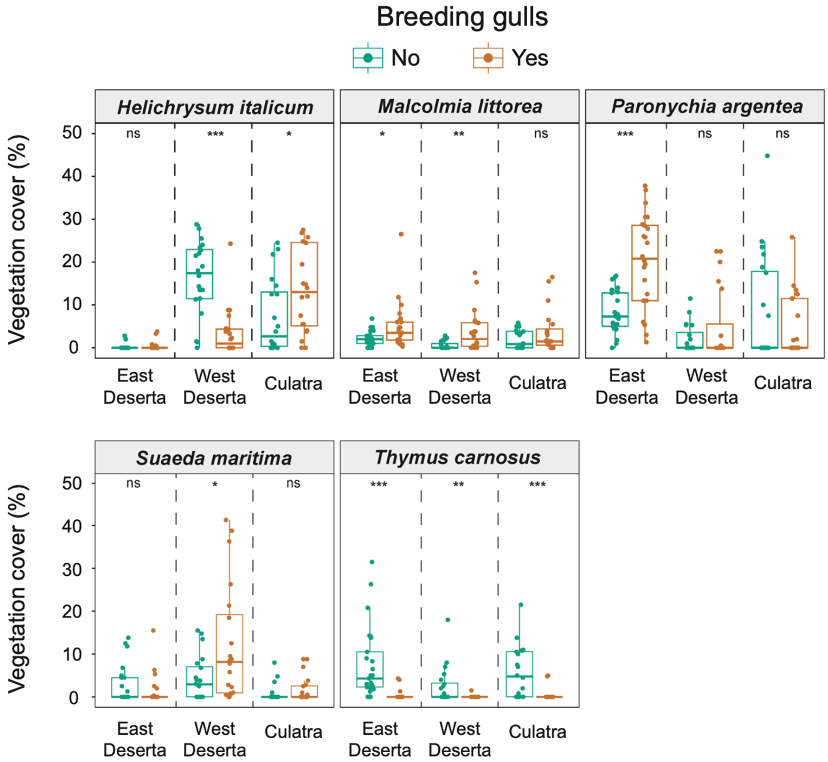

Figure 4. Jitterplots (median, 25–75% percentile range, 1.5 * inter-quantile range) of the percentage cover of plant species during spring (April 2022) with and without breeding yellow-legged gulls *Larus michahellis* among sites (East Deserta Island, where gulls have been breeding for the past 13 years; West Deserta Island and Culatra Island, where gulls have been breeding for the past 3 years). Median, 25–75% percentile range, 1.5 * inter-quantile range. ns: non-significant; *: p-value ≤ 0.05; **: p-value ≤ 0.01; ***: p-value ≤ 0.001.

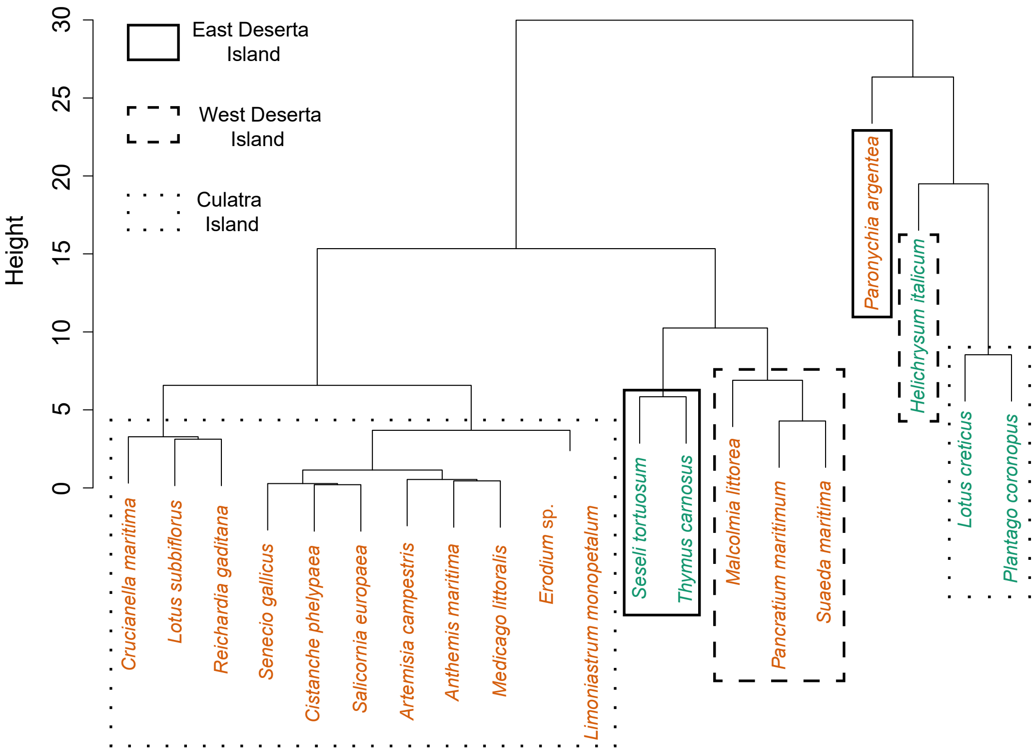

Figure 5. Hierarchical clustering of plant species composition in areas with (orange) and without (green) breeding yellow-legged gulls *Larus michahellis* among colony sites (East Deserta Island, where

gulls have been breeding for the past 13 years; West Deserta Island and Culatra Island, where gulls have been breeding for the past 3 years). We used the Ward clustering algorithm on Euclidean distances. The boxes highlight the three colony sites, supported by long branch lengths, and also geographically coherent clusters as follows: East Deserta Island (filled rectangles); West Deserta Island (dashed rectangles): and Culatra Island (pointed rectangles).

On the contrary, the taller growing species *T. carnosus* had a significantly higher cover in areas without breeding gulls for both the old colony site and the two new colony sites (Table 1, Figure 5, namely for East Deserta Island and Culatra Island colonies, respectively (ISA: 0.49, $p < 0.001$, Figure 5). In relation to *H. italicum,* it was only present in the new colony sites (ISA: 0.49, p-value < 0.001), and was strongly related to the areas without breeding gulls at West Deserta Island (Figure 5). However, this species showed opposite patterns for West Deserta Island and Culatra Island: in West Deserta colony site it was significantly more abundant in areas without breeding gulls, whereas in the Culatra colony site it was more abundant in areas with breeding gulls (Table 1, Figure 4).

4. Discussion

Our data show that breeding yellow-legged gulls had a strong effect on the vegetation cover of the grey dune habitats of Ria Formosa, Southern Portugal. In an old colony site, where yellow-legged gulls have been breeding for the past 13 years, and with a higher number of breeding pairs, the cover by tall vegetation was substantially reduced, and the cover by short vegetation increased substantially in the areas where gulls were breeding, when compared to adjacent areas without breeding gulls. In general, our results showed that breeding gulls had a harmful effect on the percentage cover of slow-growing tall plant species, supplementing the finds of other studies with yellow-legged gulls on other habitat types or with other gull species [11,16,25,34]. Burrow nesting seabird species such as Leach's Storm-petrel *Hydrobates leucorhous* and Tufted Puffins *Lunda cirrhata*, may also affect the vegetation dynamics of breeding sites through soil eutrophication (orniteutrophication) [35,36].

In our study, the only plant species that were negatively correlated with breeding gulls were the taller plant species *T. carnosus* and *H. italicum*. These slow-growing plant species should be more adapted to soils with low content of organic matter [37], and were presumably affected by gulls through stamping. The increase in cover of short vegetation in the breeding area of the old colony site at Deserta Island, mostly by nitrophilous species (*P. argentea* and *M. littorea*) during spring, should be attributed to two factors: (1) physical disturbance and removal of tall plant species by breeding gulls, and (2) deposition of droppings by yellow-legged gulls, which make the soils richer in nutrients and thus more suitable for these fast-growing plant species. The high deposition of droppings during the breeding season may change soils' nutrient composition, particularly in phosphorous (P) and nitrogen (N) content, which may lead to a decrease in plant species diversity [16,27,38]. Such an increase in nutrients can modify the biogeochemical cycles of these nutrients and have negative impacts on terrestrial vegetation and aquatic water bodies, mainly through orniteutrophication or plant ruderalisation, as seen in the strong increase of *M. littorea* in our study, and by the increase in annual and bi-annual plant species, including graminoid ruderal species in this and other studies [25,39,40].

According to our results, major changes in vegetation cover and composition should occur only after 3 years of consecutive breeding by yellow-legged gulls in the same area. During the first years of breeding, gulls should have minor impacts on the vegetation, attributed to their general physical disturbance activities such as stamping, plant uprooting and pulling of stems and leaves for nest building [16,38]. However, as consecutive annual breeding continues in the same area, physical disturbance of vegetation, seed dispersal of exotic plant species [16,41] and changes in soil chemistry through defecation [42,43] will inevitably lead to changes in physiognomy and composition of plant communities, including the local extinction of native plant species [11,15,16,18,27,44]. Chemical alterations in arid areas, such as the grey dunes of our study site, may be particularly strong [38,45], and future studies should compare detailed soil analysis between areas with and without breeding gulls.

Gulls tend to establish large breeding colonies on cliffsides or sandy coastal areas, and the increase of these colonies changes the vegetation dynamics of the original habitat [46]. Talavera et al. [40] computed an index, using true colour orthophotos and orthomosaics derived from Unmanned Aerial Systems (UAS), for Deserta Island (including our study area) and showed that the breeding pressure of both yellow-legged gull and Audouin's gull *Ichthyaetus audouinii* were directly implicated in the perturbation of the native vegetation of the grey dunes of Deserta Island. Our study shows that such perturbations occur only after 3 years of consecutive breeding in the same area, and changes in vegetation composition should be largely initiated with the destruction of tall and slow-growing plant species by breeding gulls. However, vegetation cover is an important factor for ground nesting seabirds since it can protect eggs and chicks from predators, as well as from daily heat gain or nocturnal heat loss when the birds are not incubating [47,48]. This means that gulls change their exact nesting area, as the vegetation cover decreases to very low levels (pers. observations). Therefore, the local vegetation dynamics of the grey dunes are associated with changes in the spatial distribution of breeding gulls [40]. This certainly deserves further studies in order to fully understand the changes in the local vegetation dynamics of grey dune areas and therefore their resilience to increasingly frequent climate change events, such as sea level rise and heat waves.

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