

**Diogo Filipe Gonçalves Portela**

**The impact of the Yellow-legged gull *Larus michahellis* on the biota  
of their nesting dune habitats of Ria Formosa**



**UNIVERSITY OF ALGARVE**

Faculty of Sciences and Technologies

2021/2022

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on the biota of their nesting dune habitats of Ria  
Formosa**

**Master's in Marine Biology**

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## **Agradecimentos**

Em primeiro lugar, quero agradecer aos meus orientadores Professor Doutor Jaime Ramos e Professora Doutora Ester Serrão por toda a ajuda, paciência e disponibilidade pelos comentários e revisões feitas ao longo da escrita desta tese. O meu muito obrigado por poder ter tido esta oportunidade de trabalhar com uma equipa incrível e num tema interessante e inovador para mim.

Ao Professor Doutor Vítor Paiva e ao Doutor Jorge Pereira pela ajuda disponibilizada para a análise estatística e pelas sugestões de melhorias na escrita da tese.

À equipa do Ecotop Mare-UC (Ecology and Conservation of Top Predators) e aos meus colegas de campo Rafael e Jorge pelo companheirismo e apoio durante o trabalho de campo.

Ao Mestre Alves pelas tardes e momentos passados e pelas histórias e conhecimentos partilhados e ensinados nas mais diversas áreas.

À empresa ANIMARIS e a todo o staff pelo transporte disponibilizado até à Ilha Deserta.

Aos meus colegas de mestrado Ioannis Emmanouil Choulis e Ana Alves Silva pela ajuda disponibilizada durante a recolha de dados no campo e aos voluntários do primeiro ano de mestrado (Ariadne Vafiadou, Joana Reves, Marzi Ellen, Patrícia Nunes, e Rita Gomes) pela ajuda e disponibilidade para monitorizar as crias de Gaivota-de-Audouin. Sem eles, a recolha de dados não teria acabado mais cedo, como tal o meu obrigado pela ajuda disponibilizada por todos.

Aos meus colegas de mestrado por todo o apoio, paciência e companheirismo desde o início desta aventura e pelas amizades criadas. O meu muito obrigado!

Por fim, um muito obrigado à minha família, em especial aos meus pais e avós, pelo apoio incondicional, pelo esforço que tiveram para me deixar seguir o caminho que decidi tomar e por ficarem orgulhosos de ter alcançado os meus objetivos e patamares!

## Resumo

O aumento da população mundial e conseqüente urbanização levaram a uma progressão da redução e fragmentação dos habitats naturais devido aos impactos das pressões antropogénicas nos ecossistemas, sendo que as aves marinhas foram um dos grupos mais afetados. As aves marinhas são um grupo de aves que têm vindo a diminuir drasticamente ao longo dos últimos anos, nomeadamente devido a atividades humanas, como a sobrepesca com o uso de redes de emalhar e a poluição dos oceanos, e também pelo aumento das alterações climáticas. No entanto, alguns grupos de aves marinhas têm vindo a aumentar exponencialmente ao longo dos anos, nomeadamente os membros pertencentes à família Laridae, família esta que inclui as gaivotas, devido ao facto de apresentarem uma dieta plástica e de terem adaptado as suas atividades com o ambiente urbano. Dentro das espécies que mais tem aumentado nesta família destaca-se a Gaivota-de-patas-amarelas *Larus michahellis*. A Gaivota-de-patas-amarelas é uma ave marinha oportunista, de grande porte e de hábitos diurnos que apresenta uma grande área de dispersão e tem vindo a aumentar exponencialmente durante as últimas décadas na América do Norte e na Europa, especialmente no Mediterrâneo, onde a maior parte das áreas costeiras estão dominadas por esta espécie. Os maiores núcleos desta espécie na Europa são nas Ilhas Marseille em França, no Arquipélago Baleárico em Espanha e na Ilha da Berlenga em Portugal. A conseqüente adaptação destas ao meio urbano fez com que tomassem proveito de infraestruturas humanas para nidificarem nas grandes cidades, e de fontes externas de alimentação, nomeadamente de descargas de peixe em portos de pesca ou de lixo existente nas lixeiras ou nos esgotos, diminuindo assim o esforço de procura de alimento para as crias e aumentando assim a taxa de sucesso reprodutor. No entanto, o aumento das populações urbanas de Gaivotas-de-patas-amarelas começaram a provocar interações negativas com outras espécies de fauna e de flora em habitats adjacentes ao meio urbano, e a um aumento dos conflitos com o homem devido ao seu comportamento agressivo durante a época de nidificação, barulho e lixo que provocam nos meios urbanos. Além disso, sendo espécies generalistas e fenotipicamente maiores, provocam impactos negativos e danos em outras populações de aves simpátricas, predando os ovos ou competindo por melhores locais de nidificação, sendo que também afetam a vegetação e as espécies florísticas nos locais onde formam grandes colónias nidificantes, pelo aumento excessivo de nutrientes no solo, pela introdução de sementes de espécies invasoras ou pela deposição de metais pesados nos solos. No geral, devido ao

grande aumento desta espécie e devido ao seu comportamento agressivo e impactos que podem provocar nos seus habitats, são consideradas como uma peste e um grande problema ecológico.

No presente estudo, foram analisados os efeitos de uma colónia antiga e de duas mais recentes de Gaivotas-de-patas-amarelas na cobertura vegetal de diferentes tipos de vegetação (total, viva alta/baixa e morta alta/baixa) e nas espécies de plantas nos habitats de dunas cinzentas na Ria Formosa, nomeadamente nas Ilhas Deserta e Culatra. Quadrados de vegetação foram usados para recolher dados sobre a cobertura de vegetação em áreas com e sem gaivotas a nidificar. *Paronychia argentea*, *Helichrysum italicum*, *Thymus carnosus*, *Suaeda maritima* e *Malcolmia littorea* foram as espécies vegetais mais significativas encontradas em ambas as áreas. Análises com recurso a Modelos Lineares Generalizados (GLM) foram usados para avaliar os efeitos do local das colónias de Gaivotas-de-patas-amarelas, da época e da sua interação nos diferentes tipos de vegetação e espécies. Além disso, foram avaliados os efeitos potenciais desta mesma espécie nas taxas de sucesso reprodutor de duas espécies de aves marinhas migradoras que nidificam no mesmo habitat, a Gaivota-de-Audouin *Ichtyaetus audouinii* e a Andorinha-do-mar-anã *Sternula albifrons*. Para a primeira espécie, três subcolónias diferindo em cobertura de vegetação e presença de Gaivotas-de-patas-amarelas a nidificar (uma zona com vegetação alta e uma com vegetação baixa de controlo e uma de vegetação alta com confluência por parte das patas-amarelas) foram escolhidas e foram acompanhadas desde o início da época de nidificação, sendo que na subcolónia dominada por vegetação mais alta e com Gaivotas-de-patas-amarelas a nidificar em conjunto com as Audouin, foi montado um abrigo para observar possíveis interações entre as duas espécies: 1) Cleptoparasitismo, 2) Ataques aéreos e contra-ataques, 3) Intrusão nos ninhos, 4) Predação dos ovos e 5) Predação das crias. Os ninhos foram devidamente marcados com estacas numeradas, os ovos medidos com o auxílio de uma craveira e depois a primeira cria de cada ninho foi acompanhada durante cinco dias, tendo sido tirado o peso em cada dia para depois aplicar-se um modelo de regressão quadrático a cada uma das crias de modo a medir a sua taxa de crescimento nesta fase do ciclo de vida. Para as andorinhas-do-mar, câmaras de foto-armadilhagem foram colocadas em locais estratégicos perto dos ninhos das mesmas em duas colónias independentes, Fuseta e Barrinha, Praia de Faro, que também foram acompanhadas desde o início da época de nidificação, de modo a observar possíveis interações entre ambas as espécies. Os resultados obtidos mostraram que as Gaivotas-de-

patas-amarelas afetavam negativamente a percentagem de cobertura vegetal de quase todos os tipos de vegetação nas áreas onde nidificam e induziam o crescimento e o aparecimento de espécies ruderais e gramíneas, tais como a *Malcolmia littorea* ou a *Paronychia argentea*, e que este efeito era mais evidente na colónia mais antiga localizada na Ilha Deserta, mostrando o papel de modificador ecológico das mesmas nas áreas onde se estabelecem. Nas andorinhas-do-mar-anãs, não foi possível determinar um efeito negativo da Gaiivota-de-patas-amarelas. Por outro lado, as baixas interações, nomeadamente de predação de ovos e crias, registadas a partir do abrigo mostraram que as Gaiivotas-de-patas-amarelas não representavam uma ameaça para a subcolónia de Gaiivotas-de-Audouin, mas podem representar para colónias em áreas com pouca cobertura de vegetação, uma vez que as crias estavam mais expostas a potenciais predadores devido à falta de cobertura de vegetação, refletindo isso em taxas de crescimento mais reduzidas na área com pouca cobertura de vegetação, mostrando que a densidade da vegetação em torno dos ninhos tem um papel importante para a sobrevivência das crias de gaiivotas que nidificam no solo.

## Abstract

The Yellow-legged gull *Larus michahellis* is a well-studied seabird that has been increasing exponentially across the Europe and North America, especially on the Mediterranean region, over the last decades. Due to its aggressive and sedentary behaviour, its abundance and ecological role on their habitats, they can be considered as a threat to local fauna and flora. In this study, it was evaluated the effects of old and recent resident Yellow-legged gull populations on the grey dune vegetation and plant species percentage cover on different colonies and seasons, as well as the effects on the breeding success of two migratory sympatric seabirds, Audouin gull *Ichthyaetus audouinii* and Little tern *Sternula albifrons*, on the Ria Formosa Barrier Islands (Deserta and Culatra Islands). Sampling squares were used to measure the percentage cover in areas with and without breeding gulls. *Paronychia argentea*, *Helichrysum italicum*, *Thymus carnosus*, *Suaeda maritima* and *Malcolmia littorea* were the most significant species found on both areas. GLM analysis was used to assess the effects of the Yellow-legged gull on the types of vegetation and plant species. In addition, three sub-colonies of Audouin gull differing in vegetation cover were monitored and a hide was erected in an area with tall vegetation and nearby nesting Yellow-legged gulls. Camera traps were placed in strategic places in two different colonies of Little terns to record interactions between both species, but without success. Results showed that Yellow-legged gulls affected the vegetation cover of most types of vegetation on their breeding grounds and induced the growth of ruderal and graminoid plant species, like *Malcolmia littorea*. Interactions recorded from the hide showed that Yellow-legged gulls do not pose a significant threat on the defined sub-colony of Audouin gulls but could be a potential threat in the areas with low vegetation cover, where chicks may not hide efficiently and be predated by Yellow-legged gulls.

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## List of abbreviations, acronyms, and symbols

SPA- Special Protected Area

YLG- Yellow-legged gull

AG- Audouin's gull

LT- Little tern

GF- Greater flamingo

CP- Common puffin

AT- Arctic terns

RT- Roseate tern

CT- Common tern

*Lm- Larus michahellis*

*Cr- Croicocephalus ridibundus*

*Lo- Larus occidentalis*

*Lm1- Larus marinus*

*Ld- Larus delawarensis*

*Lc- Larus cachinnans*

*Ls- Larus schistisagus*

*Hp- Hydrobates pelagicus*

*La- Larus argentatus*

*Sh- Sterna hirundo*

*Lf- Larus fuscus*

*Fa- Fratercula arctica*

*Lc1- Larus crassirostris*

# Chapter 1: Introduction

## 1. The impact of opportunistic species on other biota

The increase of the human population and consequent rapidly growing urbanization have led progressively to a reduction and fragmentation of natural habitats due to the impact of anthropogenic pressures on ecosystems. Such impacts originated 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 (Chauhan, 2014; Evans et al., 2009; Furst et al., 2018; Samia et al., 2015). Because of the changes in the natural landscapes originated from an increase in urbanization, urban areas became suitable habitats for a wide variety of species, including mammals, reptiles and birds, that possess the ability to adapt to these new fragmented habitats by becoming more tolerant to the presence of humans and the disturbance from their daily activities (Bateman & Fleming, 2012; Kitchen et al., 2010). Synurbization, i.e., the capacity of animals to adapt to urban habitats, can be beneficial to some species, because of the increase in food sources and shelter from predators, potentially leading to higher adult survival and breeding rates. However, many populations of these species are non-native/exotic and overpopulated in urban areas due to their opportunistic and gregarious behaviour. Well-known examples of species that adapted well to urban habitats are the House sparrow *Passer domesticus*, White-winged doves *Zenaida asiatica*, gulls *Larus sp.*, Red foxes *Vulpes vulpes* and even Brown anoles *Anolis sagrei* (Ditchkoff et al., 2006; French et al., 2018; Lapiedra et al., 2017; Samia et al., 2015; Spelt et al., 2019; Wandeler et al., 2003; West, 1993). Exotic species that adapt well to urban areas may also alter the genomic pool of native species through hybridization, like the Egyptian goose *Alopochen aegyptiaca*, which has been increasing in urban parks and started to interbreed with native duck and goose species (Callaghan & Brooks, 2016; Swardt, 2010).

The strong increase in populations of opportunistic species increase may lead to negative interactions and conflicts with humans and impact native vulnerable species and habitats adjacent to urban areas (French et al., 2018; Mikula et al., 2014; Schwemmer et al., 2008). These adjustments are particularly evident in generalist species with higher phenotypic and behavioural plasticity, such as larids, allowing them to overcome the challenges of a novel environment by, for instance, adapting and exploiting food sources derived from anthropogenic activities, such as fisheries and landfills, and by using the urban areas as

nesting grounds, becoming less vulnerable to predation and potentially increasing their reproductive success (Fuirst et al., 2018; Schwemmer et al., 2008; Spelt et al., 2019) (figure 1.1). The increase of the Yellow-legged gull (YLG) *Larus michahellis* populations throughout Europe is linked to an increase in negative interactions both with humans and wildlife (Pais de Faria et al. 2021). The first involves noise and pollution in cities, contamination of water sources by the transmission of pathogens and parasites, like *Salmonella sp.*, and aggressive behaviour towards humans during the reproductive period. The second involves competition for food, habitat, and nesting sites with other coastal seabirds, ruderalization of the vegetation and changes in soil nutrients (Arcos et al., 2001; Belant, 1997; Benussi & Fraissinet, 2020; Peña-Lastra et al., 2022; Migura-Garcia et al., 2017).

Opportunistic species such as gulls can have several impacts on native species, mainly through competition for food, habitat and nesting sites, the proliferation of diseases, and other ecological problems associated with them, whether in terrestrial or aquatic environments (Gyimesi & Lensink, 2012). The increase of some gull species, such as the Yellow-legged gull, can be an important threat to vulnerable populations of seabirds breeding on small coastal inlets and colonies, like the common tern *Sterna hirundo*, as well as to native plant species, by being seed dispersers of alien plant species or by changing nutrients composition through deposition of heavy metals and guano (Bays, 1997; Donehower et al., 2007; Gyimesi & Lensink, 2012; Martín-Vélez et al., 2022; Matías & Ruiz, 2003).



Figure 1.1: Adult of YLG *Larus michahellis* feeding from a trash container in an urban area (source: Armindo Veiga).

## 1.1 The demographic expansion of Yellow-legged gull populations

Seabirds are a well known studied marine group, thus being known as good indicators of “long-term and large-scale changes on the marine environments” and despite the global decrease of this group, mainly due to human activities, such as fisheries and pollution, and the increase of climate changes, some groups of seabirds have been increasing drastically throughout the years, especially the Laridae family members due to their opportunistic and adaptable behaviour towards urbanization (Croxal et al., 2015; Paleczny et al., 2015; Parsons et al., 2008; Schreiber, 2002).

Gulls *Larus* spp. are known to be gregarious larids that live in large colonies with other sympatric seabird species, been classified as top avian predators on ecological food webs, and their populations have increased enormously in the last decades, especially due to the increase of external food sources from open dumps and discharges from fisheries, and due to their plastic diet, thus modifying and adapting their foraging strategies in different areas (Ceia et al., 2014; Oro & Martinez-Vilalta, 1994; Westerberg et al., 2019).

In general, the species belonging to the Laridae family are known to be very aggressive, both intra-specifically and inter-specifically, cohabitating with other larid and seabirds or wader species during the breeding season, where most of the larger gulls show dominance and are considered top predators on the food webs, like the Great black-backed gull *Larus marinus*, meaning that they may influence and control the population size of other smaller

seabird species, like auks or petrels, and even of populations from smaller gull species such as the Audouin's gulls *Ichthyaetus audouinii* (Oro & Martinez-Vilalta, 1994; Furness, 2012; Matias & Catry, 2010; Veitch et al., 2016).

The YLG is a large and opportunistic seabird with diurnal habits that has a large area of dispersion and that has been increasing exponentially during the last decades in North America and Europe, especially in the Mediterranean region over the last 30 years, where most coastal areas are now overpopulated by this species (Arcos et al., 2001; Duhem et al., 2003; Ramos et al., 2009, Pais de Faria et al., 2022). In southern Europe, with around 5000 islands and islets in the Mediterranean, the YLG populations have been increasing exponentially since 1980, mainly on small inhabited coastal islands close to the mainland, such as Marseille islands in France, the Balearic archipelago in Spain and Berlenga island in Portugal. Such demographic explosion has generated negative effects on coastal ecosystems, both on animal and plant populations (Conover & Miller, 1976; Spelt et al., 2021; Vidal et al., 1998).

The increase of the YLG populations in many places may be derived from the fact that they adapted to urbanised areas and that their diet is variable and not strictly dependent on fish or crustaceans like other gull species, such as the Audouin's gull, thus having easier and larger food resources throughout the whole season, being that the knowledge of their ecology and foraging strategies on urban areas is still very slight (Méndez et al., 2020; Oro & Martínez-Abraín, 2007; Pais de Faria et al., 2021). Being an opportunistic species, they have taken advantage of external food sources released from the fisheries' discards and from the open refuse dumps or sewage waste from human activities. These food resources may be particularly important during the inter-breeding period, which has contributed to an increase in their survival rates, but also during the chick-rearing period, which is an important factor to explain the increasing in breeding success (Bosch et al., 1994; Bosch et al., 2000; Ceia et al., 2014; Duhem et al., 2003; Vidal et al., 1998).

## **1.2 The impacts of gulls on vulnerable fauna and flora**

Animals can choose areas and habitats that will maximize their fitness and net energy gains by adaptation of their foraging strategies toward temporal and spatial variations (Spelt et al., 2021). For ground-nesting seabirds, such as gulls, vegetation plays a major role in the choice of the nesting site because it provides shelter from predators or

neighbouring individuals, as well as protection and shade from higher temperatures for the young chicks, thus increasing chick survival and overall breeding performance (Kim & Monaghan, 2005; Miyazaki, 1996). However, a very large density of gulls in an area will damage the vegetation with their daily activities, like faecal materials, pellets, stamping or pecking of plant species for nest building (Signa et al., 2012; Sobey, 1976) (figure 1.2).

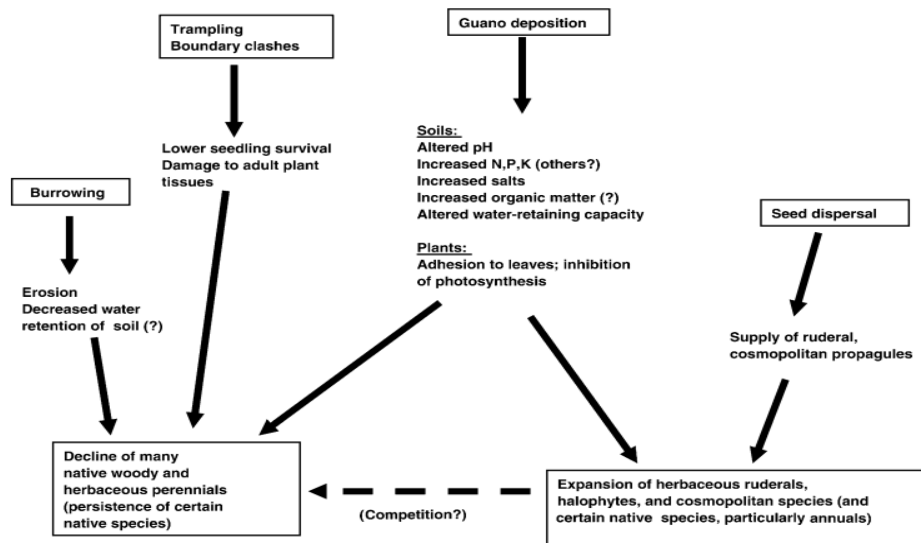


Figure 1.2: Examples of ecological mechanisms in which seabirds can affect the dynamics of the soils and plant species (Ellis, 2005).

The high deposition of “guano” during the breeding season changes the nutrient composition of the soil, particularly phosphorous (P) and nitrogen (N). The changes in the biogeochemical cycles of these nutrients may lead to soil eutrophication, with consequent negative impacts on terrestrial vegetation and aquatic water bodies through runoff. Changes in the flora species have been associated with the deposition of ammonia (NH<sub>3</sub>) by gulls through defecation, thus promoting the appearance of nitrophilous species, threatening native flora species reported in some previous studies, like *Stachys brachyclada* (Pérez, 1998; Vidal et al., 1998). Some previous studies have shown that gulls have favored the development of nitrophilous plant species in the Riou Archipelago, such as *Lavatera arborea*. Furthermore, the increase of the number of breeding pairs on a colony of Slaty-backed gull *Larus schistisagus* has promoted the damage of a great part of the plant cover on the Shelikan island, mainly due to pecking and plugging of plants for nest construction, consequently decreasing and driving to local extinction of a wide

variety of vascular plants, e.g., *Gymnocarpium dryopteris* and *Linnaea borealis* (Vidal et al., 1998; Zelenskaya & Khoreva, 2006). Also, other seabirds, like Auks and Northern Fulmars *Fulmarus glacialis* have impacted soil and sediment properties, as well as plant communities, in the Arctic region through the consequent accumulation of guano in the soils (Xu et al., 2016).

Gulls can also impact soil suitability for vegetation by other means besides eutrophication and ruderalization. Salt from the plumage of gulls, when in large amounts, can affect the composition of the soil (Otero et al., 2015; Peña-lastra et al., 2020; Vidal et al., 1998). Deposition of heavy metals on the soils, such as cadmium (Cd) or lead (Pb), is another possible damage that the gulls can bring, mainly due to their feeding behaviour on open dumps or municipal garbage dumps in cities (Peña-lastra et al., 2020).

Regarding the impacts on fauna, gulls tend to breed in huge colonies, cohabitating with other gull and seabird species along the nesting sites, and given their aggressive behaviour and higher phenotypic plasticity, they tend to be dominant in those places, competing for food and breeding sites, predated eggs and chicks or displacing the neighbouring seabirds from their breeding areas, such as the Audouin's gull, a threatened gull species, and other native waterbirds to areas more exposed to native predators (Arcos et al., 2001; Vidal et al., 1998). Terns, a smaller seabird group that includes species such as the Arctic *Sterna paradisaea* and Roseate *Sterna dougalii* terns, have been suffering from gulls' pressures, mainly from the Yellow-legged gull. These two tern species are the most reported to be affected because most of the aerial strikes made by the gulls on the terns and the eggs predated from the nests were recorded in smaller colonies and on nesting grounds with few or no surrounding dense vegetation (Cavanagh & Griffin, 1993; Donehower et al., 2007; Hernández-Matías & Ruiz, 2003).

Numerous studies have also reported predation and kleptoparasitism of eggs and chicks of other species by gulls, as well as competition for food sources or nesting grounds, such as with the Audouin gull, European storm-petrels *Hydrobates pelagicus*, Great Frigate *Phoenicopterus roseus*, Common puffin *Fratercula arctica* and Black-headed gulls *Larus ridibundus* (Arcos et al., 2001; Oro et al., 2005; Nettleship, 1972; Salathé, 1983; Skorká et al., 2014).

Overall, due to the large increase of this superabundant species group and because of their aggressive behaviour and impacts that they can make on their habitats, they have been

considered a pest and a major ecological and conservation problem (Table 1.1). This is mainly due to the negative impacts and damage that they cause on other sympatric seabird populations, by predation of nests and competition for food sources and habitat, impact on vegetation and soils where they form huge colonies, and even on human infrastructures and activities, like cities, airports, recreation, and fisheries (Arcos et al., 2001; Bosch et al., 2000; Duhem et al., 2003; Oro & Martínez-Abraín, 2007; Otero et al., 2015; Ramos et al., 2009; Vidal et al., 1998).

Table 1.1: Review of the types of impacts and respective outcomes that Larid species have on fauna and flora on different study areas.

Species	Type of impact	Outcomes	Study Area	Reference
		<i>Armeria sp.</i> populations very affected by the gulls	Isle of May, Scotland	Sobey, 1976
<i>Lm</i>	1) Stomping and pulling of plant species	Ruderalization of the vegetation and floristic changes	Atlantic Islands Natural Park of Galicia, Spain	Peña-Lastra et al., 2020
		Possible extinction of seagrass <i>Zostera marina</i>	Cies Islands, Galicia	Otero et al., 2015
<i>Cr</i>		Floristic changes on native species distribution and abundance	Vistula River, Poland	Bukaciński et al., 1994
<i>Ls</i>		Decrease and extinction of several vascular plant species	Shelikan Island, Russia	Zelenskaya & Khoreva, 2006
		Changes on soil nutrients and pH composition	Atlantic Islands Natural Park of Galicia, Spain	Peña-Lastra et al., 2022
<i>Lm</i>	2) Floristic changes	Species turnovers and immigration and extinction of some plant species	Riou archipelago, France	Baumberguer et al., 2012
		Decrease of cover percentage of herbaceous species	Frioul archipelago, France	
<i>Lo</i>			Chafarinas Islands, near Marroco	García et al., 2002
	3) Dispersion of alien species	Dispersion of seeds of alien plant species such as <i>Parietaria judaica</i>	Atlantic Islands Natural Park of Galicia, Spain	Peña-Lastra et al., 2022
<i>Lm</i>		Dispersion of seeds of alien plant species	Barcelona, Spain	Vélez et al., 2022
<i>Larus sp.</i>		Changes on soil nutrients composition	Surtsey, Iceland	Sigurdsson & Magnusson, 2010
	4) Defecation	Drift changes on vegetation dynamics by the increase of guano deposition	Bejaïa, Algeria Jijel, Algeria	Hussein et al., 2021
<i>Lm</i>		Floristic changes on native species distribution and abundance	Isle of May, Firth of Forth, Scotland	Sobey, 1976
		Changes on soil nutrients composition		

Table 1.1: Continued

Species	Type of impact	Outcomes	Study Area	Reference
		Drift changes on vegetation and soil nutrients by the deposition of guano	Marinello ponds, Italy	Signa et al., 2012
		Changes on soil nutrients composition	Calanques National Park, France	Peña-Lastra et al., 2021
		Decrease of lignin and cellulose on the plants cell wall	Cies Islands, Galicia	Otero et al., 2021
<i>Ld</i>		Drift changes on vegetation and soil nutrients by the deposition of guano	Great Lakes, Canada	Hogg & Morton, 1983
		Deposition of heavy metal compounds on soils	Cies Islands, Galicia	Otero, 1998
<i>Lc</i>		Drift changes on vegetation and soil nutrients by the deposition of guano	Chafarinas Islands, near Marroco	García et al., 2003
		Changes on soil nutrients composition	Vistula River, Poland	Bukaciński et al., 1994
<i>Ia</i>		Drift changes on vegetation and soil nutrients by the deposition of guano	Chafarinas Islands, near Marroco	García et al., 2003
		Changes on soil nutrients composition		
Species	Type of impact	Outcomes	Study Area	Reference
<i>Lm</i>	5) Eutrophication	Eutrophication of the soils were the colonies are placed	Atlantic Islands Natural Park of Galicia, Spain Cies Islands, Galicia	Peña-Lastra et al., 2020 Otero et al., 2015
		Ruderalization of the vegetation	Calanques National Park, France Riou archipelago, France Frioul archipelago, France	Peña-Lastra et al., 2021 Baumberger et al., 2012
<i>Lm</i>	6) Interspecific competition	Floristic changes on native species distribution and abundance	Isle of May, Firth of Forth, Scotland	Sobey, 1976
		Predation of AG eggs and chicks	Ebro Delta, Spain	Oro & Martínez-Vilalta, 1994
<i>Lm</i>	7) Predation	Predation of European Storm-petrels <i>Hydrobates pelagicus</i> chicks Predation <i>Hydrobates pelagicus</i> chicks	Chafarinas Islands, near Marroco Columbretes Islands, Spain Maltese Islands, Malta Benidorm Island, Spain	Martínez-Abraín et al., 2003 Borg et al., 1995 Oro et al., 2005

Species	Type of impact	Outcomes	Study Area	Reference
Lc	7) Predation	Predation of White-faced Stormpetrels <i>Pelagodroma marina</i>	Selvagem Grande, Madeira, Portugal	Matias & Catry, 2010
		Predation of endemic land snails <i>Theba macandrewiana</i>		
		Predation of eggs of Common terns <i>Sterna hirundo</i>	Ebro Delta, Spain	Hernández-Matías & Ruiz, 2003
		Predation of eggs and chicks of Greater Flamingos <i>Phoenicopteros roseus</i>	Rhône Delta, France	Salathé, 1983
		Predation of AG eggs and chicks	Chafarinas Islands, near Marroco	González-Solís et al., 1997
		Predation of eggs and chicks of GF	Rhône Delta, France	González-Solís, 2003
		Predation of Puffins nests chicks	Isle of May, Firth of Forth, Scotland	Salathé, 1983
		Predation of <i>Fratercula arctica</i> chicks	Gull Island, Newfoundland, Canada	Finney et al., 2001
		Predation of eggs of Sh		Rice, 1987
		Predation of eggs of Arctic terns <i>Sterna paradisaea</i>		
La	7) Predation	Predation of eggs of Roseate terns <i>Sterna dougalii</i>	Eastern Egg Rock, USA	Donehower et al., 2007
		Predation of Lf chicks	Söderskär bird sanctuary, Finland	Hario, 1994
		Predation of eggs and chicks of Ring-billed gulls (Ld)	Rogers city, Michigan	Southern & Southern, 1984
		Predation of Common gulls <i>Larus canus</i> chicks	Hanko Peninsula, Finland	Kilpi, 1994
Lf	7) Predation	Predation of chicks of La	Mellum Island, Germany	Wilkins & Exo, 1998
		Predation of Puffins nests and chicks	Isle of May, Firth of Forth, Scotland	Finney et al., 2001
		Predation of CP chicks	Skokholm Island, Wales	Davis & Dunn, 1976
		Predation of Leach's Storm-petrels <i>Hydrobates leucorhous</i>	Ellliðaey Island, Iceland	Hey et al., 2020
		Predation of eggs of common murre <i>Uria aalge</i>		
Lm1	7) Predation	Predation of eggs, chicks and adults of Black-legged Kittiwake <i>Rissa tridactyla</i>	Gull Island, Newfoundland, Canada	Veitch et al., 2016
		Predation of eggs of CT		
		Predation of eggs of AT		
Lm	8) Pressure	Predation of eggs of RT	Eastern Egg Rock, USA	Donehower et al., 2007
		Competition for food with AG	Ebro Delta, Spain	Arcos et al., 2001
Lc	8) Pressure	Competition for food with AG	Chafarinas Islands, near Marroco	González-Solís, 2003 González-Solís et al., 1997

Species	Type of impact	Outcomes	Study Area	Reference
		Pressure on Black-headed gulls (Cr)	Reservoir in southern Poland	Skórka et al., 2014
<i>Lm</i>		Kleptoparasitism on AG nests	Ebro Delta, Spain Ebro Delta, Spain Chafarinas Islands, near Marroco Columbretes Islands, Spain	Oro & Martínez-Vilalta, 1994 Martínez-Abraín et al., 2003
<i>Lc</i>	9) Kleptoparasitism		Ebro Delta, Spain Chafarinas Islands, near Marroco	Arcos et al., 2001 González-Solís, 2003 González-Solís et al., 1997
<i>La</i>		Kleptoparasitism on Puffins nests	Isle of May, Firth of Forth, Scotland	Finney et al., 2001
<i>Lf</i>		Kleptoparasitism on Fa nests	Gull Island, Newfoundland, Canada	Rice, 1987
<i>Lml</i>		Kleptoparasitism on Puffins nests	Isle of May, Firth of Forth, Scotland	Finney et al., 2001
		Kleptoparasitism on Fa nests	Gannet Islands, Labrador, New Zealand	Veitch et al., 2016
<i>Lcl</i>		Kleptoparasitism of Rhinoceros auklets <i>Cerorhinca monocerata</i>	Teuri Island, Japan	Miyazaki, 1996

Notes: In this review the focus was to emphasize the effects mainly from YLG, however other larid species were included. Points 1-6 refer to studies that focused on the effects of gulls on vegetation and native flora, and points 7-9 on the effect on other seabird species.

## 2. Biology and ecology of the study species

### 2.1 Yellow-legged gull

The Yellow-legged gull *Larus michahellis* is a seabird that belongs to the Charadriiformes order and to the Laridae family (Demongin, 2016). It is a relatively large gull species, with the body, rump, and head mainly white, belly, mantle, and wings greyish, and the tips of the wings are black. The legs and the eyes are yellow, with a red orbital around them, and the bill, is also yellow where the inferior part has a red dot (Svensson et al., 2009) (figure 1.3).



Figure 1.3: Adult of YLG *Larus michahellis* (source: Diogo Portela).

Yellow-legged gulls do not have sexual dimorphism; however, the males are normally larger than the females, and the juveniles are all black greyish, being difficult to distinguish from other juvenile gull species, mainly from the Lesser Black-backed gulls *Larus fuscus* (Svensson et al., 2009; Almeida, 2013). They tend to breed in colonies, between April and July, with other seabird species, mainly on cliffs, coastal islands and inlets, and dunes. They lay 1-3 eggs (Harris, 1994; Hey et al., 2020; Pérez et al., 2006). They are opportunistic omnivores and their diet includes pelagic fishes, crabs, molluscs,

insects, as well as waste generated from human activities and even marine seabirds or small mammals (Meirinho et al., 2014; Mendes et al., 2018).

This species has a large area of dispersion and has been increasing exponentially during the last decades in North America and Europe, especially in the Mediterranean region over the last 30 years, where most coastal areas are now overpopulated by this species (Arcos et al., 2001; Duhem et al., 2003; Ramos et al., 2009; Pais de Faria et al., 2022). Also, they are known to be the most abundant gull species in the southwestern Palearctic region, and the European population was estimated to have a near maximum of 1 million mature individuals in 2015 (Birdlife international, 2015; Olsen & Larson, 2004).

In Portugal, they are present all year throughout the continental coastline, especially from the Cabo Carvoeiro to the southern part of the country, and the biggest colony of Yellow-legged gulls is located on Berlenga island. In 1994 it was estimated to be around 45000 breeding individuals (Meirinho et al., 2014; Morais et al., 1994), but control measures led to a decline of the breeding population to around 13150 breeding individuals in 2013. However, with the recent start of breeding in urban areas, such as Peniche or Porto, their numbers are expected to increase even more (Meirinho et al., 2014; Pais de Faria et al., 2021).

Due to their great expansion and aggressive behaviour, YLG has started to be considered a global problem, posing threats to humans and wildlife. Therefore, control and management measures have been implemented to try to decrease their pressure and their population size (Belant, 1997; Calladine et al., 2006; Rock, 2005).

## 2.2 Audouin gull

The Audouin's gull *Ichthyaetus audouinii* is another seabird belonging to the Charadriiformes order and to the Laridae family (Demongin, 2016). It is a rare endemic medium-sized gull of the Mediterranean region, with the body and head brightly white, belly and wings clear-greyish, and the tips of the wings are black with some white dots. The legs are green-greyish, the eyes are dark and the bill is red with a black strip on the edge (Svensson et al., 2009) (figure 1.4).



Figure 1.4: Adult pair of AG *Ichthyaetus audouinii* (source: Diogo Portela).

Like the YLG, AG does not present sexual dimorphism and the criteria for the distinction between males and females is the same. The juveniles are also quite difficult to distinguish from those of other gull species (Blanco & Marchamalo, 1999; Svensson et al., 2009).

AG are strictly piscivores and are usually seen along the coastline fishing or near trawling boats. Their diet includes small pelagic fishes, like sardines *Sardina pilchardus* or anchovies *Engraulis encrasicolus* (Arcos et al., 2001; Meirinho et al., 2014).

They are a migratory species that normally breed on cliffs or on sandy beaches in huge colonies in the Mediterranean, between March and July, and one of the largest known colonies is in the Ebro Delta (figure 1.5). They lay 1-3 eggs and migrate to west Africa up to Mauritania and Senegal (García-tarrasón, 2014; Pastor et al., 1995). However, the

colonies of the Ebro Delta have been collapsing, from near 15000 pairs to 1000 pairs in 2019, due to the decrease of the fishing discards from fishing vessels on ports and due to the presence of mammal predators near the breeding colonies (Birdlife International, 2020). In Portugal, they breed only on Deserta island, Ria Formosa Natural Park, where they may be affected by the pressure from YLG that breeds in sympatry (Meirinho et al., 2014).



Figure 1.5: Distribution range of the AG (IUCN, 2022).

Despite the decreasing status of the AG populations worldwide and the decrease of the conservation status classification from least concern to vulnerable, according to the IUCN red list of threatened species, the number of breeding pairs on Deserta island has been increasing exponentially (figure 1.6), and the LIFE project (LIFE-Ilhas Barreira) that now underway aims to promote conservation actions for this species (SPEA, 2020). Nowadays the colony of AG on Deserta island is the biggest known colony of this species worldwide (CIESM, n.d).

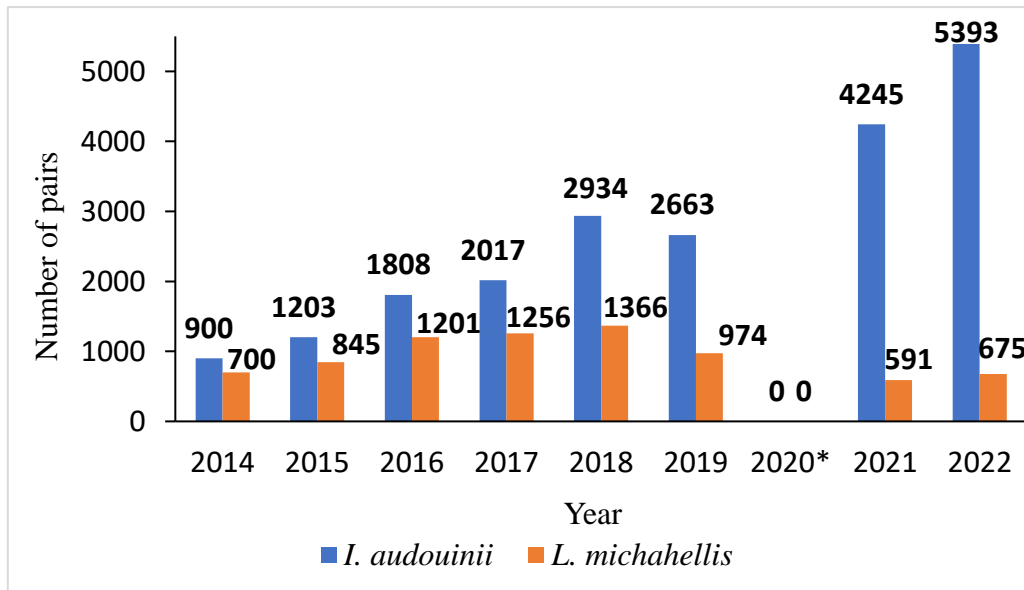


Figure 1.6: Comparison of the breeding pairs of YLG (orange) and AG (blue) on the Deserta island, Faro, from 2014-2022.

Note (\*): On the 2020 it was not made a census because of the Covid-19 pandemic.

### 2.3 Little tern

The Little tern *Sternula albifrons* is the last seabird that is going to be on focus in this work. It belongs to the Charadriiformes order and the Laridae family as well (Demongin, 2016). It is a small-sized tern that breeds through Europe, mainly in the Mediterranean region, with the body and belly clearly white, wings clear-greyish with the tips black, and the upper part of the head black. The legs and the bill are yellowish, and the tip of the bill has a black strip (Birdlife international, 2019; Svensson et al., 2009) (figure 1.7).



Figure 1.7: Breeding pair of Little terns *Sternula albifrons* (source: Diogo Portela).

They don't present sexual dimorphism, but the males are slightly bigger than females, like in most seabird species (Blanco & Marchamalo, 1999; Svensson et al., 2009). This tern species is mostly piscivorous and are usually seen along the coastline fishing, mainly on shallow waters, and their diet includes small pelagic fishes, like gobies *Pomatoschistus spp.* and sand smelts *Atherina spp.* (Catry et al., 2006; Meirinho et al., 2014; Ramos et al., 2013).

LT is a migratory species that normally breed on sandy beaches with low vegetation cover in small colonies along the Mediterranean, between May and July, where clutch size varies between 1-3 eggs as well (Birdlife international, 2019). After the breeding period, most of the European populations begin their migration in late July until late September, wintering in West Africa (Meirinho et al., 2014) (figure 1.8).



Figure 1.8: Map with the distribution range of the Little tern (IUCN, 2022).

In Portugal, this species is present during the breeding period and on the migration period after breeding. Most of the Little terns are seen and breed in the Algarve region, mainly on the barrier islands or in saltpans, however, there are records available in other places of the country, like in the saltpans of Aveiro and Tejo or Sado estuaries (Catry et al., 2004; Meirinho et al., 2014).

Despite the decreasing status of the LT populations worldwide, the trends for the European populations are still unknown (Birdlife international, 2019). However, just like for the AG, the conservation actions of the LIFE project (LIFE-Ilhas Barreira) tend to help the LT populations by analysing the state of the populations on the Ria Formosa coastal lagoon and trying to make them breed in other suitable breeding grounds, to afterwards implement more measures to help on the conservation of this species (SPEA, 2020).

### 3. Objectives

This study will evaluate the extent to which the YLG populations may impact negatively the fauna and flora of the Ria Formosa barrier islands ecosystem, a study site that contains areas of major conservation importance, classified as Special Protected Areas (SPA) for wild birds and sites for conservation importance (SICS) under the habitat's directive (Directive 92/43/CE, 21 of May) that protects all habitats and communities species on extinction pathways or threatened, such as the grey dune habitats, as well as under the bird's directive (Directive n° 79/409/CEE, 2nd of April) that protects all bird species, including migratory species such as the Audouin gull or the Little tern, that occur on a wild state on Europe and in the states members of the European Union territories (Torribio, 1999; Tozato, 2016).

So, the two main objectives of this study are the following: 1) to evaluate the effects of the Yellow-legged gull on vegetation cover and plant composition in the grey dune habitats, and 2) to evaluate the inter-specific aggression and predation pressure on two vulnerable seabird species, the Audouin gull and Little Tern *Sternula albifrons*. We compared vegetation cover and composition between areas with Yellow-legged gull nesting and adjacent areas without Yellow-legged gull nesting and evaluated interspecific aggression of breeding Yellow-legged gull on adjacent breeding Audouin gull and predation pressure on breeding Little Terns. It is expected that the Yellow-legged gulls will have a harmful impact on the abundance and cover percentage of the type of vegetation species surrounding their breeding grounds throughout the different seasons of the year, as well as a negative impact on the breeding success of Audouin gull and Little Tern populations by potential predatory and kleptoparasitic events, as well as by interference on nesting activities and chick growth on Audouin gull.

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## Chapter 2: The impact of the Yellow-legged gull *Larus michahellis* on the biota of their nesting dune habitats of Ria Formosa

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Keywords: Interspecific interactions; *Larus michahellis*; Species turnovers; Sympatric seabirds; Vegetation cover

### Abstract

The Yellow-legged gull *Larus michahellis* is a well-studied seabird that has been increasing exponentially across Europe and North America, especially in the Mediterranean region, over the last decades. Due to their aggressive and sedentary behaviour, their abundance and their ecological role in their habitats, they can be considered a threat to local fauna and flora. In this study, it was evaluated the effects of old and recent resident Yellow-legged gull populations on the grey dune vegetation and plant species percentage cover in different colonies and seasons, as well as the effects on the breeding success of two migratory sympatric seabirds, Audouin gull *Ichthyaetus audouinii* and Little tern *Sternula albifrons*, on the Ria Formosa Barrier Islands (Deserta and Culatra Islands). Sampling squares were used to measure the percentage cover in areas with and without breeding gulls. *Paronychia argentea*, *Helichrysum italicum*, *Thymus carnosus*, *Suaeda maritima* and *Malcolmia littorea* were the most significant species found in both areas. GLM analysis was used to assess the effects of the Yellow-legged gull on the types of vegetation and plant species. In addition, three sub-colonies of Audouin gull differing in vegetation cover were monitored and a hide was erected in an area with tall vegetation and nearby nesting Yellow-legged gulls. Camera traps were placed in strategic places in two different colonies of Little terns to record interactions between both species, but without success. Results showed that Yellow-legged gulls affected the vegetation cover of most types of vegetation on their breeding grounds and

induced the growth of ruderal and graminoid plant species, like *Malcolmia littorea*. Interactions recorded from the hide showed that Yellow-legged gulls do not pose a significant threat to the defined sub-colony of Audouin gulls but could be a potential threat in the areas with low vegetation cover, where chicks may not hide efficiently and be predated by Yellow-legged gulls.

## **Introduction**

The increase of the human population and consequent rapidly growing urbanization have led progressively to a reduction and fragmentation of natural habitats due to the impact of anthropogenic pressures on ecosystems. Such impacts originated 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 (Chauhan, 2014; Evans et al., 2009; Fuirst et al., 2018; Samia et al., 2015). Urban areas are suitable habitats for a wide variety of opportunistic species, including mammals, reptiles and birds, that possess the ability to adapt to these new fragmented habitats, becoming more tolerant to disturbance events and the presence of humans (Bateman & Fleming, 2012; Kitchen et al., 2010).

The strong population increase of opportunistic species leads to negative interactions and conflicts with humans and impacts on native vulnerable species and natural habitats adjacent to urban areas (French et al., 2018; Mikula et al., 2014; Schwemmer et al., 2008). These are particularly evident in generalist species with higher phenotypic and behavioural plasticity, such as gulls *Larus sp.*, allowing them to overcome the challenges of a novel environment by, for instance, adapting and exploiting food sources derived from anthropogenic activities, such as fisheries and landfills, or by using the urban areas as nesting grounds, becoming less vulnerable to predation and potentially increasing their reproductive success (Fuirst et al., 2018; Schwemmer et al., 2008; Spelt et al., 2019).

Gulls *Larus spp.* is known to be gregarious larids that live in large colonies with other sympatric seabird species, and their populations have increased enormously in the last decades, especially the Yellow-legged gull (YLG) *Larus michahellis*. In southern Europe, with around 5000 islands and islets, these species have been increasing exponentially since the decade of 80, 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. (Conover & Miller, 1976; Pais de Faria et al., 2022; Spelt et al., 2021; Vidal et al., 1998).

Such demographic explosion of the YLG populations throughout Europe is linked to a consequent increase in negative interactions with both humans and wildlife (Pais de Faria et al. 2021). The first one involves noise and pollution in cities, contamination of water sources by the transmission of pathogens and parasites, like *Salmonella sp.*, and aggressive behaviour towards humans during the gulls' reproductive period. The second involves competition for food, habitat, and nesting sites with other coastal seabirds, ruderalization of the vegetation and changes in soil nutrients (Arcos et al., 2001; Belant, 1997; Benussi & Fraissinet, 2020; Peña-Lastra et al., 2022; Migura-Garcia et al., 2017; Thomas, 1972).

Gulls can impact soil suitability by causing eutrophication and ruderalization of the surrounding vegetation and changing chemically their compositions. Changes in the flora species have been associated with the deposition of ammonia (NH<sub>3</sub>) through defecation, thus promoting the appearance of nitrophilous species, threatening native flora species reported in some previous studies, like *Stachys brachyclada* (Pérez, 1998; Vidal et al., 1998). Deposition of heavy metals on the soils, such as cadmium (Cd) or lead (Pb), mainly due to their feeding behaviour on open dumps or municipal garbage dumps in cities and even huge segregation of excessive salt from the feathers are other damages that gulls can bring to natural breeding habitats, like grey dunes, changing the properties of the soils (Otero et al., 2015; Peña-lastra et al., 2020; Vidal et al., 1998).

Regarding the impacts on fauna, gulls tend to breed in huge colonies, cohabitating with other gull and seabird species along the breeding areas. Given their aggressive behaviour and higher phenotypic plasticity, they tend to be dominant in those places, competing for the most suitable breeding sites, displacing the neighbouring seabirds from their breeding areas or by attacking birds arriving from their foraging areas or predated their eggs and chicks (Arcos et al., 2001; Martínez-Abraín et al., 2003; Oro & Martínez-Vilalta, 1994; Vidal et al., 1998). Terns, a smaller seabird group that includes species such as the Arctic *Sterna paradisaea* and Roseate *Sterna dougalii*, are the two tern species mostly reported to be affected by gulls, mainly from the YLG, because most of the aerial strikes made by the gulls on the terns and the eggs that were preyed from the nests were recorded in smaller colonies and on nesting grounds with few or no surrounding dense vegetation (Cavanagh & Griffin, 1993; Donehower et al., 2007; Hernández-Matías & Ruiz, 2003).

Numerous studies have also reported predation and kleptoparasitism of eggs and chicks of other species by gulls, as well as competition for food sources or nesting grounds, such as with the Audouin gull *Ichtyaetus audouinii*, European storm-petrels *Hydrobates pelagicus*, Great Flamingos *Phoenicopterus roseus*, Common puffin *Fratercula arctica* and Black-headed gulls *Larus ridibundus* (Arcos et al., 2001; Oro et al., 2005; Nettleship, 1972; Salathé, 1983; Skorká et al., 2014).

This study evaluated the extent to which the YLG populations impact negatively the flora and fauna of the Ria Formosa barrier islands ecosystem, a study site that contains areas of major conservation importance, classified as Special Protected Areas (SPA) for wild birds and sites for conservation importance (SICS) under the habitat's directive (Directive 92/43/CE, 21 of May) that protects all habitats and communities species on extinction pathways or threatened, such as the grey dune habitats, as well as under the bird's directive (Directive n° 79/409/CEE, 2<sup>nd</sup> of April) that protects all bird species, including migratory species that occur on the wild state on Europe and in the states members of the European Union territories (Torribio, 1999; Tozato, 2016). The two main objectives are the following: 1) to evaluate the effects of the breeding Yellow-legged gulls on vegetation cover and plant composition in the grey dune habitats, and 2) to evaluate the inter-specific aggression and predation pressure on two vulnerable seabird species, the Audouin gull and Little Tern *Sternula albifrons*.

## Methods

### Study area

The study was made mainly on three sand-dune barrier islands of the Ria Formosa Natural Park, Algarve Portugal: Deserta or Barreta Island (36° 57' 56.61" N, 7° 52' 21.4752" W), Culatra Island (36° 59' 20" N, 7° 50' 25" W) and Fuseta Island (37° 02' 36.888" N, 7° 44' 43.35"W) (figure 2.1). These islands are included in the Portuguese Network of Protected Areas by the Decree-law n° 373/1987, to protect and conserve the fauna, flora, habitats and all of the Ria Formosa lagoon system, which is listed in the Ramsar Convection (Amaral, 2009; Ceia, 2007; Ceia et al., 2010; Costa, 2015). In this area, there are groups of Yellow-legged gulls and Audouin gulls that breed in sympatry (Deserta Island), as well as colonies of Little terns.



Figure 2.1: Geographic area of the RFNP, including the Deserta, Culatra and Farol islands (red arrows). (source: Costa, 2015; ICNF, 2015)

## Impacts on the vegetation

A comparison of the vegetation cover in areas with nesting Yellow-legged gulls with similar adjacent areas without nesting gulls was made to evaluate the impact of this resident species on the surrounding vegetation. Firstly, the vegetation cover was measured in areas where Yellow-legged gulls nested since 2010-2013, and in similar adjacent areas without nesting gulls, in the East Deserta island colony. Four sampling periods, one for each season were made in 2020-2022: Spring (April 2021), Summer (June 2021), Autumn (September 2021) and Winter (February 2020). A similar approach was used for the Culatra colony and the West Deserta Island colony, but only for the Spring of 2022 (March-April). These two colonies were occupied by Yellow-legged gulls since 2018. The comparison between the effects of gulls on East Deserta and on these two last colonies enables to assess of whether a colony established for a longer period has more detrimental effects on the vegetation types and plant species.

To assess seasonal variation in vegetation cover in areas with and without breeding gulls 25 squares of 5m<sup>2</sup> each were marked in East Deserta. For each season (Spring, Summer, Autumn, and Winter) total vegetation cover, percentage cover of short (< 5 cm) and tall (>5 cm) of dead and alive vegetation was recorded using a 1m<sup>2</sup> quadrat placed in each one of the 4 corners of each 5m<sup>2</sup> square. In the Spring of 2022, 20 squares of 5m<sup>2</sup> each were established on Culatra and West Deserta to assess also similarly the percentage cover of the total, short and tall dead or alive vegetation, as well as the abundance of native and alien plant species that were present in areas with and without nesting Yellow-

legged gulls (Figure 2.2). The percentage cover of native and alien plant species was also assessed on the 25 squares marked on the East Deserta colony during Spring.



Figure 2.2: Example of a vegetation square with three vegetation species: a) *Malcolmia littorea*, b) *Paronychia argentea* and c) *Lotus creticus*.

## Impacts on sympatric migratory seabirds

### Audouin Gulls

To evaluate the aggressive behaviour of the Yellow-legged gulls towards sympatric Audouin gulls, a bird hide was mounted from the beginning of the breeding season and the behaviours of the Yellow-legged gulls towards the Audouin's gull were recorded. On Deserta Island ca. 5400 pairs of Audouin gull and ca. 700 pairs of Yellow-legged gull breed there in 2022 (authors, own data). The hide was placed early in the laying season, around mid-April, so that the gulls got used to it. Observations were made from the hide for about 2 h per day (1 hour in the morning and 1 h in the afternoon) when the birds were incubating the eggs and later when feeding young chicks, to record detailed aggressive behaviours and predation events of sympatric Yellow-legged gulls. Five different types of interactions were defined, similar to the ones used by Oro and Martinez-Vilalta (1994): 1) Aerial kleptoparasitism, when a Yellow-legged gull chased an Audouin gull to induce regurgitation and consequent drop of the food; 2) Aerial strikes, when a Yellow-legged gull or Audouin gull tried to attack an individual during flight; 3) Ground intrusions, when a Yellow-legged gull entered on the Audouin gull sub-colony and near a nest, provoking

an alarm call by the last; 4) Egg predation, when a Yellow-legged gull pecked an egg or consumed it and 5) Chick predation, when a Yellow-legged gull attempted to catch a fledgling chick or on the nest. The hatching success and early chick growth (until the age of 5 days) for the Audouin's gulls' nesting was also measured on areas differing in vegetation cover towards the Yellow-legged gulls' pressure was trying to be assessed. The rationale is that the predation by Yellow-legged gulls on Audouin's gull nests and small chicks could be influenced by vegetation cover because the small chicks depend on the vegetation for hiding and protection towards predators and heat. To assess these, three areas were selected: one area of nesting Audouin's gull with high vegetation cover close to the Yellow-legged gull nesting area, and two control areas (A=with high vegetation cover, B=with low vegetation cover) away from nesting Yellow-legged gulls. For each area, around 50 nests were marked, the eggs were measured with callipers and the chicks weighed every day with a spring balance. The breadth and length of the eggs were registered, the egg volume content (Egg volume (cm<sup>3</sup>) =K\* L\*B<sup>2</sup>, where K=0,4866, L=length (mm) and B=breadth (mm)) and the egg shape index (S=100\* B/L) whereas therefore calculated for each area with the formula used by (Coulson 1963). Hatching success (%) per area was calculated as the number of eggs that hatched / the total number of eggs laid for each individual nest. For the chick growth rates, a quadratic regression model was fitted after obtaining the body mass weights of each first hatched chick on the first five days of age ( $M_d = M_0 + ad + bd^2$ , where  $M_d$  = chick mass on day d,  $M_0$ = estimated chick mass on day 0, d =age in days, a = linear growth, b = quadratic growth parameter) to retrieve some parameters that could describe the growth and therefore preview possible survival rates of the early chicks (Ramos, 2001). The chicks that were found dead near the nests, mainly by pecking's on the chest or that disappeared before the fifth day of monitoring were not used to obtain regression models and were considered as preyed by Yellow-legged gulls.

## **Little terns**

For the nesting colonies of Little terns, camera traps were used to monitor and register nest predation and evaluate the proportion of disturbed incubating individuals and predated nests by passing Yellow-legged gulls. The hatching success of the Little terns' chicks and possible predation events were checked on the study colonies. Also, observations of possible interactions between the two species, like was done for the

Audouin gulls, were registered opportunistically between the two species when monitoring the colonies. To assess breeding success, 60 nests were numbered with wooden tongue sticks on Fuseta island, a place with lesser pressure of YLG, and 40 nests on Barrinha, Praia de Faro (36° 59' 65" N, 7° 57' 84" W), a place with higher pressure of YLG. The hatching success (%) for the Little terns was calculated as the number of eggs that hatched / the total number of eggs laid for each colony. Also, a total of 6 camera traps per area were placed in strategic places to try to register possible predation events or other interactions between the gulls and the terns.

### **Statistical analysis**

Generalized Linear Models (GLMs) were used to evaluate the effect of the presence of YLG in East Deserta Island (areas with and without nesting YLG), season (Spring, Summer, Autumn and Winter) and their interaction with the percentage cover of dead and alive short and tall vegetation. The response variable was the percentage cover of the different types of vegetation (total, dead low/alive and tall low/alive). GLMs were also used to assess the effect of the presence of YLG on vegetation type during spring for the recent colonies of West Deserta and Culatra, for one model the response variable was the same as for the East Deserta and for the other it was the plant species that were found in both sites with and without gulls. Regarding the impacts on sympatric seabird species, one-way ANOVAs were used to compare egg size, egg volume, egg shape, hatching success and early growth parameters between the control area with high vegetation cover, control area with low cover and confluence area with high cover and nearby breeding YLG on East Deserta for the Audouin gulls. Interactions between species (YLG vs AG and YLG vs LT) and the clutch size and hatching success of the Little terns between Fuseta and Barrinha, Praia de Faro were also compared with one-way ANOVAs, being that for the statistical analysis of the hatching success for the two species it was calculated the breeding success of each individual clutch. Chick growth rate for the Audouin gulls was obtained with the aid of a fitted quadratic regression model, being that each early growth parameter (M0, Linear growth and Quadratic growth) was obtained for each first hatched chick and one-way ANOVA was used to see statistical differences between the defined areas. All data was previously checked for normality (Shapiro-Wilk normality test) and homogeneity of variances (Levene test). Percentage cover data were arcsin-

transformed ( $\arcsin(\sqrt{x/100})$ ) to meet parametric assumptions to perform the GLMs (Steel & Torrie, 1980).

GLMs with a quasibinomial error distribution and logit link was used to test the effects of the presence of nesting Yellow-legged gulls, individual season and colony site, and their interaction on each type of vegetation cover and species cover for each study area and for the Spring of 2022, separately. Statistical analyses were conducted within the R environment v. 4.2.0 (R Core Team 2022). All data are shown as mean  $\pm$  SD (standard deviation) unless mentioned otherwise. Differences were considered statistically significant at a  $p$  value  $\leq 0.05$ .

## **Results**

### **Seasonal variation in vegetation cover on old established colonies of Yellow-legged gulls**

Table 2.1 shows the seasonal variation in vegetation cover for East Deserta Island and the Spring of 2022 for the remaining study areas. All different types of vegetation differed between areas with breeding and non-breeding gulls on the East Deserta colony. GLM models results showed that the presence of Yellow-legged gulls was positively associated with the percentage cover of dead low vegetation ( $t = 11.06$ ;  $p = <0.001$ ), and negatively associated with tall vegetation, both dead and alive ( $t = -5.61$ ;  $p = <0.001$  and  $t = -7.12$ ;  $p = <0.001$ ). For each season, the effect was mostly negatively associated, when compared with the autumn season, particularly for the winter season when all types of vegetation cover were negatively related to the presence of nesting Yellow-legged gulls. The interaction between presence the of nesting Yellow-legged gulls and each season was similar in terms of negative and positive association for each type of vegetation, inducing that the presence of gulls would influence the vegetation cover of each type of vegetation (Table 2.2).

Table 2.1: Seasonal variation on the percentage of vegetation cover for East Deserta Island (see methods), and for the spring of 2022 for East Deserta, West Deserta and Culatra Islands. Values are shown as mean  $\pm$  SD.

	Total vegetation (%)	Dead low vegetation (%)	Dead tall vegetation (%)	Alive low vegetation (%)	Alive tall vegetation (%)
<b>East Deserta Island</b>					
YLG nesting					
Spring 2021	77.2 $\pm$ 16.39	8.09 $\pm$ 1.96	6.33 $\pm$ 2.75	35.25 $\pm$ 14.86	27.53 $\pm$ 6.73
Summer 2021	74.33 $\pm$ 15.42	31.15 $\pm$ 16.80	0.73 $\pm$ 1.95	11.36 $\pm$ 3.65	31.09 $\pm$ 9.48
Autumn 2021	70.23 $\pm$ 15.59	20.66 $\pm$ 10.56	12.64 $\pm$ 12.72	14.07 $\pm$ 4.69	22.86 $\pm$ 9.01
Winter 2020	13.13 $\pm$ 5.48	3.93 $\pm$ 3.30	2.43 $\pm$ 3.49	5.73 $\pm$ 4.03	1.04 $\pm$ 1.71
YLG not nesting					
Spring 2021	70.59 $\pm$ 15.35	8.73 $\pm$ 6.61	3.02 $\pm$ 3.38	34.25 $\pm$ 14.04	24.59 $\pm$ 9.11
Summer 2021	83.90 $\pm$ 16.90	38.69 $\pm$ 22.43	1.44 $\pm$ 1.16	6.79 $\pm$ 2.77	36.98 $\pm$ 9.59
Autumn 2021	84.56 $\pm$ 17.04	63.91 $\pm$ 18.35	1.09 $\pm$ 1.27	16.08 $\pm$ 5.76	3.48 $\pm$ 5.37
Winter 2020	23.18 $\pm$ 6.92	3.76 $\pm$ 2.06	6.51 $\pm$ 2.78	4.24 $\pm$ 2.34	8.87 $\pm$ 5.03
<b>Spring 2022</b>					
East Deserta Island					
YLG nesting	57.21 $\pm$ 14.24	12.78 $\pm$ 4.69	8.57 $\pm$ 5.37	31.57 $\pm$ 12.73	4.29 $\pm$ 4.08
YLG not nesting	56.13 $\pm$ 10.52	5.79 $\pm$ 2.66	12.97 $\pm$ 4.90	18.51 $\pm$ 6.20	18.86 $\pm$ 7.35
West Deserta Island <sup>1</sup>					
YLG nesting	67.12 $\pm$ 14.71	6.37 $\pm$ 2.29	14.97 $\pm$ 5.99	14.83 $\pm$ 6.13	30.96 $\pm$ 11.44
YLG not nesting	69.09 $\pm$ 18.05	8.18 $\pm$ 3.17	17.3 $\pm$ 10.09	16.54 $\pm$ 8.02	27.08 $\pm$ 18.96
Culatra Island <sup>1</sup>					
YLG nesting	86.69 $\pm$ 16.02	10.79 $\pm$ 5.56	22.48 $\pm$ 11.13	20.25 $\pm$ 7.24	33.18 $\pm$ 9.81
YLG not nesting	72.67 $\pm$ 12.26	8.33 $\pm$ 4.19	15.26 $\pm$ 9.18	17.29 $\pm$ 10.27	31.81 $\pm$ 10.32

<sup>1</sup> Newly established colony

Table 2.2: Generalized Linear Model (GLM) results for the percentage of each type of vegetation (total vegetation, dead low/tall and alive low/tall) at East Deserta Island. Parametric coefficients are also shown (Estimate  $\pm$  SD and t test) and significant results ( $p \leq 0.05$ ) are in italics. The reference categories are respectively non-nesting areas and Autumn season.

Response Variable	Explanatory variable	Estimate $\pm$ SD	t test	p-value
Total vegetation	YLG nesting (yes)	0.84 $\pm$ 0.25	3.35	<0.001
	Spring	-0.17 $\pm$ 0.19	-0.87	0.38
	Summer	0.79 $\pm$ 0.25	3.19	0.002
	Winter	-2.06 $\pm$ 0.23	-8.95	<0.001
	YLG nesting (yes): Spring	-0.96 $\pm$ 0.29	-3.29	0.011
	YLG nesting (yes): Summer	-1.43 $\pm$ 0.36	-4.01	<0.001
	YLG nesting (yes): Winter	-1.53 $\pm$ 0.37	-4.16	<0.001
Dead low	YLG nesting (yes)	1.91 $\pm$ 0.17	11.06	<0.001
	Spring	-1.25 $\pm$ 0.19	-6.27	<0.001
	Summer	0.89 $\pm$ 0.17	5.14	<0.001
	Winter	-1.89 $\pm$ 0.31	-6.09	<0.001
	YLG nesting (yes): Spring	-1.44 $\pm$ 0.26	-5.54	<0.001
	YLG nesting (yes): Summer	-2.25 $\pm$ 0.24	-9.54	<0.001
	YLG nesting (yes): Winter	-1.87 $\pm$ 0.43	-4.34	<0.001
Dead tall	YLG nesting (yes)	-2.58 $\pm$ 0.46	-5.61	<0.001
	Spring	-0.02 $\pm$ 0.17	-0.12	0.9
	Summer	-2.29 $\pm$ 0.41	-5.66	<0.001
	Winter	-0.73 $\pm$ 0.23	-3.19	0.02
	YLG nesting (yes): Spring	1.74 $\pm$ 0.49	3.56	<0.001
	YLG nesting (yes): Summer	1.89 $\pm$ 0.80	2.36	0.02
	YLG nesting (yes): Winter	1.55 $\pm$ 0.57	2.69	0.008
Alive low	YLG nesting (yes)	0.16 $\pm$ 0.19	0.84	0.4
	Spring	0.66 $\pm$ 0.16	4.21	<0.001
	Summer	-0.81 $\pm$ 0.23	-3.48	<0.001
	Winter	-1.31 $\pm$ 0.27	-4.8	<0.001
	YLG nesting (yes): Spring	0.28 $\pm$ 0.22	1.28	0.2
	YLG nesting (yes): Summer	0.41 $\pm$ 0.31	1.33	0.18
	YLG nesting (yes): Winter	0.16 $\pm$ 0.36	0.44	0.66
Alive tall	YLG nesting (yes)	-2.11 $\pm$ 0.29	-7.12	<0.001
	Spring	0.02 $\pm$ 0.14	0.13	0.89
	Summer	0.68 $\pm$ 0.16	4.36	<0.001
	Winter	-1.11 $\pm$ 0.21	-5.27	<0.001
	YLG nesting (yes): Spring	1.52 $\pm$ 0.32	4.72	<0.001
	YLG nesting (yes): Summer	1.84 $\pm$ 0.33	5.57	<0.001
	YLG nesting (yes): Winter	-0.12 $\pm$ 0.59	-0.2	0.84

## **Spring vegetation cover on newly established colonies of Yellow-legged gulls**

On the newly established colony sites on West Deserta and Culatra Islands, there were no differences in vegetation cover for each type of vegetation between areas with and without breeding gulls (Table 2.1). The results of the GLM model that evaluated the effects of the presence of nesting Yellow-legged gulls, new and old colony sites (East/West Deserta and Culatra), and their interaction with each type of vegetation cover showed that the presence of nesting Yellow-legged gulls was negatively associated with the percentage cover of all types, but it was only significant for the total vegetation and alive low vegetation ( $t = -2.95$ ;  $p = 0.004$  and  $t = -2.27$ ;  $p = 0.024$ ). The colony site with nesting Yellow-legged gulls was also negatively associated with the percentage cover for each type of vegetation and showed that Culatra Island had less vegetation cover for most types of vegetation than on both East and West Deserta. The interaction between the colony site and the nesting Yellow-legged gulls was, in general, positively correlated with the percentage cover of most of the types of vegetation, and both colony sites of the Deserta Island had more percentage cover than the Culatra colony site, both in areas with and without nesting gulls (Table 2.3)

Table 2.3: Generalized Linear Model (GLM) results for the percentage of each type of vegetation (total vegetation, dead low/high and alive low/high) at East Deserta, West Deserta and Culatra Islands for the springtime of 2022. Parametric coefficients are also shown (Estimate  $\pm$  SD and  $t$  test) and significant results ( $p \leq 0.05$ ) are in italics. The reference categories are respectively non-nesting areas and Culatra Island.

Response Variable	Explanatory variable	Estimate $\pm$ SD	$t$ test	$p$ -value
Total vegetation	YLG nesting (yes)	-0.75 $\pm$ 0.19	-2.95	<i>0.004</i>
	Deserta East	-1.48 $\pm$ 0.25	-6.29	<i>&lt;0.001</i>
	Deserta West	-1.01 $\pm$ 0.24	-4.07	<i>&lt;0.001</i>
	YLG nesting (yes): Deserta East	0.79 $\pm$ 0.31	2.55	<i>0.01</i>
	YLG nesting (yes): Deserta West	0.82 $\pm$ 0.33	0.82	<i>0.01</i>
Dead low	YLG nesting (yes)	-0.27 $\pm$ 0.15	-1.79	0.08
	Deserta East	-0.66 $\pm$ 0.15	-4.26	<i>&lt;0.001</i>
	Deserta West	-0.56 $\pm$ 0.16	-3.46	<i>&lt;0.001</i>
	YLG nesting (yes): Deserta East	1.14 $\pm$ 0.21	5.47	<i>&lt;0.001</i>
	YLG nesting (yes): Deserta West	0.54 $\pm$ 0.23	2.38	<i>0.02</i>
Dead tall	YLG nesting (yes)	-0.17 $\pm$ 0.17	-0.99	0.32
	Deserta East	-0.08 $\pm$ 0.15	-0.53	0.59
	Deserta West	-0.35 $\pm$ 0.17	-2.03	<i>0.05</i>
	YLG nesting (yes): Deserta East	-0.72 $\pm$ 0.24	-2.95	<i>0.04</i>
	YLG nesting (yes): Deserta West	0.29 $\pm$ 0.24	1.2	0.23
Alive low	YLG nesting (yes)	-0.44 $\pm$ 0.19	-2.27	<i>0.024</i>
	Deserta East	-0.63 $\pm$ 0.19	-3.32	<i>0.002</i>
	Deserta West	-0.47 $\pm$ 0.19	-2.38	<i>0.019</i>
	YLG nesting (yes): Deserta East	1.57 $\pm$ 0.26	6.02	<i>&lt;0.001</i>
	YLG nesting (yes): Deserta West	0.60 $\pm$ 0.28	2.13	<i>0.035</i>
Alive tall	YLG nesting (yes)	-0.04 $\pm$ 0.18	-0.24	0.81
	Deserta East	-0.74 $\pm$ 0.18	-4.03	<i>&lt;0.001</i>
	Deserta West	-0.08 $\pm$ 0.18	-0.46	0.65
	YLG nesting (yes): Deserta East	-1.60 $\pm$ 0.34	-4.7	<i>&lt;0.001</i>
	YLG nesting (yes): Deserta West	-0.16 $\pm$ 0.26	-0.61	0.54

## Cover of native and alien species on old and new established colonies of Yellow-legged gulls

For all areas, 18 different plant species were registered during the spring period of 2022, with only Culatra Island having all the catalogued species. When comparing areas with and without nesting gulls for each colony site, the number of plant species was higher in the areas without gulls, with the exception of the West Deserta island (14 species in areas with gulls vs 12 species in areas without gulls) (Table S1). The percentage cover of most plant species in each colony site was higher for the areas without nesting gulls, with the opposite observed for the West Deserta colony site as well. However, only 5 native species (*Helichrysum italicum*, *Malcolmia littorea*, *Paronychia argentea*, *Suaeda maritima* and *Thymus carnosus*) were used for statistical analysis, because these were the most dominant species that coexisted in both areas, with and without gulls, in each colony site. The most dominant species that were found in areas with nesting gulls were undergrowth species like *Malcolmia littorea* and *Paronychia argentea* (e.g,  $4.91 \pm 5.25$  % and  $21.42 \pm 12.46$  %, respectively on East Deserta), and outside gull nesting areas taller plant species such as *Suaeda maritima* or *Thymus carnosus* were dominant (e.g.,  $12.17 \pm 13.35$  and  $7.62 \pm 8.19$ , respectively) (Table 2.4).

The results of the GLM model showed that the presence of nesting Yellow-legged gulls was positively associated with the percentage cover of most plant species, apart from *Paronychia argentea* ( $t = -1.3$ ;  $p = 0.19$ ) and *Thymus carnosus* ( $t = -3.12$ ;  $p = 0.002$ ). The colony site was similar in terms of positively and negatively associated with the percentage cover of all species, showing that, overall, the percentage cover of some species in Culatra island was similar with both East and West Deserta, with the same outcome occurring for the interaction between colony site and the nesting Yellow-legged gulls (Table 2.5)

Table 2.4: Comparison of vegetation cover percentage for the species that were found in areas with and without nesting Yellow-legged gulls for Deserta East, Deserta West and Culatra Islands for the Spring of 2022. Values are shown as mean  $\pm$  SD.

	<i>Helichrysum italicum</i>	<i>Malcolmia littorea</i>	<i>Paronychia argentea</i>	<i>Suaeda maritima</i>	<i>Thymus carnosus</i>
<b>East Deserta Island</b>					
YLG nesting	0.34 $\pm$ 0.97	4.91 $\pm$ 5.25	21.42 $\pm$ 12.46	1.28 $\pm$ 3.33	0.38 $\pm$ 1.14
YLG not nesting	0.19 $\pm$ 0.66	2.09 $\pm$ 1.67	8.06 $\pm$ 4.75	2.51 $\pm$ 4.23	7.62 $\pm$ 8.19
<b>West Deserta Island</b>					
YLG nesting	16.22 $\pm$ 8.48	0.58 $\pm$ 0.91	2.09 $\pm$ 3.27	4.39 $\pm$ 5.07	2.53 $\pm$ 4.32
YLG not nesting	3.48 $\pm$ 5.62	3.87 $\pm$ 4.89	4.88 $\pm$ 8.29	12.17 $\pm$ 13.35	0.08 $\pm$ 0.33
<b>Culatra Island</b>					
YLG nesting	13.46 $\pm$ 9.49	3.75 $\pm$ 4.88	5.03 $\pm$ 7.19	1.76 $\pm$ 2.93	0.49 $\pm$ 1.47
YLG not nesting	7.26 $\pm$ 8.43	2.09 $\pm$ 2.16	8.44 $\pm$ 12.33	0.87 $\pm$ 2.07	5.76 $\pm$ 5.95

Table 2.5: Generalized Linear Model (GLM) results for the percentage cover of each type of specie (*Helichrysum italicum*, *Malcolmia littorea*, *Paronychia argentea*, *Suaeda maritima* and *Thymus carnosus*) at each area site (East Deserta, West Deserta and Culatra Islands) for the springtime of 2022. Parametric coefficients are also shown (Estimate  $\pm$  SD and  $t$  test) and significant results ( $p \leq 0.05$ ) are in italics. The reference categories are respectively non-nesting areas and Culatra Island.

Response Variable	Explanatory variable	Estimate $\pm$ SD	$t$ test	$p$ -value
<i>Helichrysum italicum</i>	YLG nesting (yes)	0.69 $\pm$ 0.27	2.52	<i>0.013</i>
	Deserta East	-3.71 $\pm$ 1.17	-3.16	<i>0.002</i>
	Deserta West	0.91 $\pm$ 0.27	3.41	<i>&lt;0.001</i>
	YLG nesting (yes): Deserta East	-0.13 $\pm$ 1.47	-0.09	0.93
	YLG nesting (yes): Deserta West	-2.37 $\pm$ 0.44	-5.39	<i>&lt;0.001</i>
<i>Malcolmia littorea</i>	YLG nesting (yes)	0.60 $\pm$ 0.40	1.5	0.13
	Deserta East	0.003 $\pm$ 0.43	0.008	0.99
	Deserta West	-1.30 $\pm$ 0.68	-1.9	0.06
	YLG nesting (yes): Deserta East	0.28 $\pm$ 0.53	0.53	0.59
	YLG nesting (yes): Deserta West	1.34 $\pm$ 0.76	1.75	0.08
<i>Paronychia argentea</i>	YLG nesting (yes)	-0.55 $\pm$ 0.42	-1.3	0.19
	Deserta East	-0.05 $\pm$ 0.36	-0.14	0.88
	Deserta West	-1.46 $\pm$ 0.57	-2.55	<i>0.012</i>
	YLG nesting (yes): Deserta East	1.68 $\pm$ 0.52	3.29	<i>0.0013</i>
	YLG nesting (yes): Deserta West	1.43 $\pm$ 0.74	1.92	0.06
<i>Suaeda maritima</i>	YLG nesting (yes)	0.72 $\pm$ 0.86	0.83	0.41
	Deserta East	1.08 $\pm$ 0.79	1.35	0.18
	Deserta West	1.66 $\pm$ 0.77	2.15	<i>0.03</i>
	YLG nesting (yes): Deserta East	-1.41 $\pm$ 1.07	-1.31	0.19
	YLG nesting (yes): Deserta West	0.38 $\pm$ 0.94	0.41	0.68
<i>Thymus carnosus</i>	YLG nesting (yes)	-2.52 $\pm$ 0.80	-3.12	<i>0.002</i>
	Deserta East	0.30 $\pm$ 0.29	1.02	<i>0.31</i>
	Deserta West	-0.86 $\pm$ 0.42	-2.07	<i>0.04</i>
	YLG nesting (yes): Deserta East	-0.54 $\pm$ 1.14	-0.48	0.63
	YLG nesting (yes): Deserta West	-1.02 $\pm$ 2.16	-0.48	0.64

## Impacts on sympatric birds

Table 2.6 shows all the interactions registered between Yellow-legged gulls with both Audouin gulls and Little terns in the different study areas. Camera traps did not reveal any interaction between Yellow-legged gulls with the other two species. On Deserta Island, observations made from the hide registered four different types of interactions, with aerial strikes by the Yellow-legged gulls on Audouin gulls being the highest recorded event (n=31). As for the Little terns, retaliation by them on attacking Yellow-legged gulls was the highest recorded event in the different colony areas, with Barrinha, Praia de Faro the place with the highest rate, but being the interaction rates of retaliation by Little terns and the aerial strikes by Yellow-legged gulls were not statistically significant between areas ( $\chi^2 = 1.19$ ,  $p = 0.28$ ) (Table 2.7).

Table 2.6: Interaction rate per hour recorded from the hide by the YLG towards sympatric Audouin gull's species on the East Deserta Island. Values are shown as rates (number of interactions/ hour).

Interactions	East Deserta	
	N	Rate
Total number of effort hours (h)	29	
Aerial kleptoparasitism	-	
Aerial strikes YLG	31	1.07
Retaliation by AG	25	0.86
Ground intrusions	9	0.31
Egg predation	8	0.28
Chick predation	-	

Table 2.7: Interaction rates per hour recorded by the YLG on sympatric Little terns on the Farol and Fuseta islands and on Barrinha, Praia de Faro. Values are shown as interaction rates (number of interactions/ hour).

	Farol	Rate	Fuseta	Rate	Barrinha Praia de Faro	Rate
Interactions	N		N		N	
Total number of effort hours (h)	8		3		3	
Aerial kleptoparasitism	-	-	-	-	-	-
Aerial strikes YLG	4	0.63	3	0.67	12	4
Retaliation by LT	16	2	5	1,33	13	4,33
Egg predation	-	-	-	-	-	-
Chick predation	-	-	-	-	-	-

Regarding the reproductive parameters of the Audouin gulls in the three designated areas on East Deserta Island, significantly higher clutch size and reproductive success were registered in the control area with a high percentage of vegetation cover (Table 2.8). It should be noted that the egg-volume and the egg-shape index for the control area with a low percentage of vegetation cover were significantly smaller, as well as the hatching success ( $F_{2,385} = 15.68, p = <0.001$ ;  $F_{2,385} = 8.25, p = <0.001$  and  $\chi^2 = 59.16, p = <0.001$ ), suggesting that the group of Audouin gulls that established on that area could be composed by mostly new and inexperienced reproductive pairs (Table 2.8). There were significant differences in the estimated mass at day 0 (M0:  $F_{1,61} = 4.34, p = < 0.05$ ) and in the quadratic growth rate ( $F_{1,61} = 4.40, p = <0.05$ ) between the confluence and the control area of high vegetation cover with Yellow-legged gull and post hoc Tukey tests showed that there were statistical differences between the high cover areas for almost all parameters, including egg-volume content, suggesting that the nearby presence of Yellow-legged gulls might have influenced the growth rate of Audouin gull chicks and that the individuals that were there established have a low breeding quality rate (table 2.9). As for the Little terns, the clutch size was similar between the two areas, and the hatching success was higher on Fuseta Island than on Praia de Faro, but the difference was not statistically significant ( $F_{1,91} = 2.69; p = 0.1$ ) (Table 2.10).

Table 2.8: Clutch size (eggs/clutch), egg length (mm), egg breadth (mm), egg volume (cm<sup>3</sup>), egg shape index (S) and hatching success (%) measured in each area. Values are shown as mean  $\pm$  SD and significant values ( $p \leq 0.05$ ) are in italics.

East Deserta Island Parameters	Control area with high cover		Control area with low cover		Confluence area with high cover and YLG nesting		Statistic	p-value
	N		N		N			
Clutch size (eggs/clutch)	144	2.88 $\pm$ 0.33	116	2.03 $\pm$ 0.66	133	2.61 $\pm$ 0.57	$F_{2,155} = 33.73$	<0.001
Length (mm)	144	64.47 $\pm$ 2.32	116	64.41 $\pm$ 2.89	133	64.17 $\pm$ 2.75	$F_{2,385} = 0.454$	0.64
Breadth (mm)	144	44.55 $\pm$ 1.18	116	43.40 $\pm$ 1.41	133	44.02 $\pm$ 1.25	$F_{2,385} = 25.23$	<0.001
Egg volume (cm <sup>3</sup> )	144	62.32 $\pm$ 4.25	116	59.12 $\pm$ 4.81	133	60.56 $\pm$ 4.59	$F_{2,385} = 15.68$	<0.001
Egg shape index (S)	144	69.18 $\pm$ 2.86	116	67.52 $\pm$ 3.77	133	68.71 $\pm$ 3.29	$F_{2,385} = 8.25$	<0.001
Hatching success (%) <sup>1</sup>	144	93.33 $\pm$ 16.15	116	26.49 $\pm$ 42.49	133	76.79 $\pm$ 38.02	$\chi^2 = 56.94$	<0.001

<sup>1</sup> N<sup>o</sup> of eggs that hatched/total of eggs laid for each clutch

Table 2.9: Early growth parameters of the Audouin gull chicks for the three defined areas. Values are in mean  $\pm$  SD and significant values ( $p \leq 0.05$ ) are in italics.

	Control area with high cover		Confluence area with high cover		Control area with low cover		Statistic	<i>p</i> -value
	N		N		N			
East Deserta Island	N		N		N			
Early growth parameters								
M0 (g)	41	42.21 $\pm$ 19.6	22	27.05 $\pm$ 23.97	4	48.42 $\pm$ 6.99	$F_{1,61} = 4.34$	<i>&lt; 0.05</i> <sup>1</sup>
Linear growth (g day <sup>-1</sup> )	41	4.86 $\pm$ 5.01	22	2.23 $\pm$ 3.35	4	0.14 $\pm$ 4.29	$F_{1,61} = 0.99$	0.32 <sup>1</sup>
Quadratic growth (g day <sup>-1</sup> )	41	1.77 $\pm$ 1.34	22	0.71 $\pm$ 0.89	4	2.09 $\pm$ 0.81	$F_{1,61} = 4.40$	<i>&lt; 0.05</i> <sup>1</sup>

<sup>1</sup> The chicks from Control area with low cover were not used for the statistical analysis, because the sample size was too small, as very few eggs hatched.

Table 2.10: Clutch size (eggs/clutch) and hatching success (%) of the breeding Little terns on Fuseta Island and on Barrinha, Praia de Faro. Values are shown as mean  $\pm$  SD.

Parameters	Fuseta		Barrinha, Praia de Faro		Statistic	<i>p</i> -value
	N		N			
Clutch size (eggs/clutch)	60	2.78 $\pm$ 0.45	41	2.63 $\pm$ 0.66	$F_{1,99} = 1.81$	0.2
Hatching success (%) <sup>1</sup>	60	70.24 $\pm$ 45.25	41	53.15 $\pm$ 49.35	$F_{1,91} = 2.69$	0.1

<sup>1</sup> N° of eggs that hatched/total of eggs laid for each clutch

## Discussion

### Effects on the vegetation

In this study, the effect of nesting Yellow-legged gulls on vegetation cover and plant composition in the grey dune habitats was examined, assessing the effect of nesting gulls on older and recently established colony sites. GLM analysis showed that on the older colony site, breeding Yellow-legged gulls had a harmful effect on the total vegetation cover during all seasons- When comparing older and newer established colonies, GLM analysis suggested that nesting Yellow-legged gulls negatively affected the vegetation cover, but that was not clear for all colony sites. Also, the only plant species that were negatively correlated with nesting gulls were *Paronychia argentea* and *Thymus carnosus*. The data for the older colony sites revealed that in the areas with no pressure of nesting Yellow-legged gulls the percentage cover of total vegetation was higher than that in the areas with nesting gulls. However, the percentage of dead vegetation was higher in the areas with nesting gulls, suggesting a negative effect of nesting gulls on the vegetation. Moreover, during spring, areas with nesting gulls registered a higher percentage cover of alive low vegetation, presumably because the soils on the breeding grounds are more suitable and richer in nutrients due to the deposition of guano, mainly for graminoid nitrophilous species, such as *Paronychia argentea* and *Malcolmia littorea*. On the other hand, taller plant species were found at a higher percentage in the areas without gulls, because these plant species generally prefer soils with low organic matter content (Costa et al., 1996). In general, we speculate that the breeding gulls have a harmful effect on the percentage cover of the different types of vegetation, as well as on the cover of the different plant species in the different colony sites, supplementing the finds of other studies with the same or similar gull species (García et al., 2003; Hogg & Morton, 1983; Hussein et al., 2021; Peña-Lastra et al., 2020; Peña-Lastra et al., 2022; Vidal et. al, 1998). Gulls tend to establish large nesting colonies on cliffsides or sandy coastal areas with surrounding vegetation, and the increase of these colonies changes the dynamics of the original habitat (Peña-lastra et al., 2020). Vegetation cover is an important factor for seabirds that breed on the ground since it can protect the eggs and the future chicks from predators, as well as from daily heat gain or nocturnal heat loss when the birds are not incubating (Kim & Monaghan, 2005). However, during the breeding period, damages can be made to the surrounding vegetation, mainly due to pecking and plugging of plants for nest construction, or by competition amongst individuals for the best breeding areas.

Several studies have reported the pressure effects made by the increased density of the Yellow-legged gull communities on their breeding areas on the plant species composition and percentage cover, as well as the possible extinction of some of these plant species, and increase of drift changes on the soil nutrients and properties (i.e, pH) (Hussein et al., 2021; Otero et al., 2015; Peña-Lastra et al., 2022; Sobey 1976; Vélez et al., 2022; Vidal et al., 1998).

Gulls are seabirds that have sedentary behaviour and are phenotypically bigger, thus having stronger effects on the vegetation cover and soil properties than migratory seabird species like the Audouin gull. On Deserta Island, the grey dune habitats are threatened by the consequent increase and pressure of breeding pairs of Yellow-legged gulls and Audouin gulls (Talavera et al., 2022). These gulls can cause significant damage to the island surrounding vegetation with their daily routines, mainly during the breeding season when they are building their nests by pecking and plugging different types of vegetation, and with the deposition of faecal materials (“guano”) and droplets on the soils (Signa et al., 2012; Sobey, 1976). The high deposition of guano during the breeding season may change the nutrient composition of the soils, particularly in phosphorous (P) and nitrogen (N), leading to a decrease in plant species diversity (García et al., 2003; Peña-lastra et al., 2020; Stevens et al., 2004). These consequent increases in nutrients can modify the biogeochemical cycles of these nutrients and can have consequent negative impacts on terrestrial vegetation and aquatic water bodies, mainly through soil eutrophication (“ornitotrophication”) or plant ruderalization, as seen in the great increase and growth of *Malcolmia littorea* and other graminoid ruderal species on the breeding grounds of Yellow-legged gulls, with the same outcome been seen on the older established colonies of gulls on this study (Ellis, 2005; Hogg and Morton, 1983; Lopes et al., 2021; Otero et al., 2018; Talavera et al., 2022). On the recently established colonies, the ruderal effect by the gulls and the soil properties were different, with dominant species on both nesting and non-nesting areas typical species of the grey dunes habitats (e.g. *Thymus carnosus* or *Helychrisum italicum*), showing that the time of the establishment of the gull communities is correlated with the environmental effects on the area, acting as environmental modulators that change the dynamics of the original habitat (Peña-Lastra et al., 2021). Other studies have shown that other seabirds species such as Leach’s Storm-petrel *Hydrobates leucorhous*, Tufted Puffins *Lunda cirrhata*, Slaty-backed gulls *Larus schistisagus* or Western gulls *Larus occidentalis* affected the dynamics of the soils through

“ornitotrophication”, as well as the vegetation cover and plant species turnovers the same way that Yellow-legged gulls did on the study areas (Duda et al., 2020; García et al., 2002; Mocholova & Khoreva, 2013; Zelenskaya & Khoreva, 2006).

### **Effects on sympatric birds**

Another aspect that was studied was the effect of the pressure of the Yellow-legged gull on two sympatric breeding seabird species. The number of interactions of breeding Yellow-legged gulls on sympatric Audouin gulls in an area with taller vegetation cover was very low, with no detection of kleptoparasitic events or chick predation. These records suggest that the Yellow-legged gulls could not be considered a threat to the Audouin gulls, although the number of hours of observation (n=29 h) was very low when compared with other similar studies regarding interactions between gulls and other seabird species (González-Solís, 2003 (n=465 h); Fuchs, 1977; Martínez-Abraín et al., 2003 (n= 545h); Spear, 1993 (n=1324 h). The number of breeding Yellow-legged gulls on Deserta Island has been decreasing strongly, partly attributed to the death of breeding adults attributed to botulism (Casero et al. 2022). The death of breeding adults was firstly reported in 2018 (pers. Observations). Therefore, the impact of the Yellow-legged gull breeding population on sympatric seabird species should have decreased in recent years.

Yellow-legged gulls have a plastic diet and accessible food sources such as open dump refuses and fisheries discharges (Calado et al., 2018; Furness et al., 1992; Mendes et al., 2018), these may be possible explanations for the low kleptoparasitic and predation events on Audouin gulls, complementing the findings of Oro and Martinez-Vilalta (1994). Gulls tend to breed in large colonies, cohabitating with other gull and seabird species along the nesting sites, and given their aggressive behaviour and higher phenotypic plasticity, they tend to be dominant in those places, competing for food and breeding sites, predated eggs and chicks or displacing the neighbouring seabirds from their breeding areas and other native waterbirds to areas more exposed to native predators (Arcos et al., 2001; Vidal et al., 1998). Some of these behaviours were seen on the study sites towards other seabird species, mainly Audouin gulls and Little terns, such as aerial strikes when the birds started to forage, or predation of eggs at the beginning of the breeding season.

Reproductive parameters of Audouin's gull differed significantly among areas differing in vegetation cover and the nearby presence of breeding Yellow-legged gulls. In areas with taller vegetation cover hatching and chick survival rates were significantly higher than those in areas with low vegetation cover, suggesting that vegetation cover plays an important role in chick survival. Early growth parameters of the Audouin chicks were also significantly higher in the areas with tall vegetation cover and almost null in the area with low cover. Areas with taller vegetation cover were dominated by denser species such as *Thymus carnosus* and *Suaeda maritima* that could offer shade, acclimation of the nests and protection to the young chicks, whereas in the low cover areas the dominant species were graminoid, mainly *Malcolmia littorea*, with the nests becoming more exposed to predators and heat. The pressure of the Yellow-legged gulls could interact in a complex way with vegetation cover and individual quality in offering protection to eggs and chicks of Audouin gull. In fact, in the area with low vegetation cover, the egg size and egg volume and clutch size were lower than in the areas with higher cover, as well as the hatching success, suggesting that individuals with lower quality occupied the area with low vegetation cover. The fact that the egg shape and volume were significantly lower for the area with low cover suggests that that area was mostly occupied by young breeders; younger female gulls are known to lay smaller eggs due to having an underdeveloped oviduct (Coulson 1963). Moreover, the fact that chick growth rates in areas of tall vegetation were higher than in the control area (i.e. without nesting Yellow-legged gulls nearby), suggests a possible interference of Yellow-legged gulls on the early chick growth parameters in the confluence area, since the egg-volume and egg shape-index were similar between the two tall vegetation areas.

Many factors contribute to seabird reproductive success, such as food availability, competition, and quality of the nesting habitat (Arcos et al., 2001; Delgado et al., 2021). Egg volume content and egg-shape index are two parameters that are correlated with possible higher chick body mass and that better parental care induces higher hatching success rates (Bolton, 1991; Blackmer et al., 2004; Delgado et al., 2021). Taken altogether, the findings of this study suggest that vegetation can affect the breeding performance of ground-nesting seabirds, contrasting with the findings of Delgado et al. (2021), and favouring studies that showed that vegetation cover induced higher breeding success in some Larid species by offering more cover to predators and protection to heat

and adverse weather conditions (Kim & Monaghan, 2005; Parsons, 1982; Parsons & Chao, 1983; Rodway & Regehr, 1999).

Little terns tend to breed on sandy areas, especially beaches, since they provide better habitats, for both food availability and less vegetation cover for the establishment of the breeding pairs (Paiva et al., 2006; Lopes et al., 2015). Previous studies have determined that the main threats to the reproductive success of Little terns were human pressure and consequent predation by *Larus sp.* (Catry et al., 2004; Fuchs, 1977; Hatch, 1970; Medeiros et al., 2007). However, few interactions between Yellow-legged gulls and Little terns were recorded in the different areas, with both areas having both human and gull disturbance along the breeding period; kleptoparasitism and predation rates on the Little terns' nests were not found on the visits to the colonies and neither on the camera traps, but retaliation by the Little terns on Yellow-legged gull strikes was lower on the area that had more gulls. These observations could suggest that the Little terns' colony on Barrinha have adapted their behaviour towards the gulls' presence, becoming more tolerable to them and that other factors, like human disturbance or other kinds of predators (e.g cats), may have caused negative effects on the reproductive successes of the colonies (Catry et al., 2004; Fujita et al., 2009).

## **Conclusions**

Overall, our results provide evidence of the effects that Yellow-legged gulls have on the vegetation cover and on the plant species turnovers on both old and recent colonies on the islands of the Ria Formosa Coastal Lagoon. Also, the low predation and kleptoparasitism rates seen in the study areas and the consequent increase of the Audouin gulls colony and decrease of the Yellow-legged gulls on Deserta Island, suggest that the presently Yellow-legged gulls have a low negative impact on the Audouin gull population. Vegetation cover can be considered an important factor for the breeding success of migratory seabirds like the Audouin gull. Future studies should increase the sample size for direct observations from hides in relation to nesting areas differing in vegetation cover for both Audouin gulls and Little terns. This would enable us to detect more interactions between both species with the Yellow-legged gull. In addition, a comparison of the plant species and soil properties and macronutrient content among

areas should be to see the changes in the habitat dynamics and ruderalization on the recent breeding Yellow-legged gull colonies.

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## List of Supplementary Material

Table 1: List of the catalogued species of each colony site and their percentage cover on the areas with and without nesting YLG. The species in red were the most abundant in each place and the ones that were used for the statistical analysis. Values are shown as mean  $\pm$  SD.

East Deserta			West Deserta			Culatra Island		
Specie	Areas with gulls	Areas without gulls	Specie	Areas with gulls	Areas without gulls	Specie	Areas with gulls	Areas without gulls
<i>Artemisia campestris</i>	0,4 $\pm$ 1,96		<i>Crucianella maritima</i>	0,25 $\pm$ 1,09	2,63 $\pm$ 3,27	<i>Anthemis maritima</i>	0,28 $\pm$ 1,19	0,5 $\pm$ 2,17
<i>Crucianella maritima</i>		0,08 $\pm$ 0,39	<i>Erodium sp.</i>	4,32 $\pm$ 5,92	0,1 $\pm$ 0,34	<i>Artemisia campestris</i>	0,52 $\pm$ 1,93	0,38 $\pm$ 1,52
<i>Helichrysum italicum</i>	0,34 $\pm$ 0,97	0,19 $\pm$ 0,66	<i>Helichrysum italicum</i>	3,48 $\pm$ 5,62	16,22 $\pm$ 8,48	<i>Cistanche phelypaea</i>		0,04 $\pm$ 0,17
<i>Lotus creticus</i>		0,78 $\pm$ 1,28	<i>Lotus creticus</i>	3,38 $\pm$ 3,76	4,13 $\pm$ 5,09	<i>Crucianella maritima</i>	3,69 $\pm$ 4,59	1,89 $\pm$ 3,28
<i>Malcolmia littorea</i>	4,91 $\pm$ 5,28	2,09 $\pm$ 1,67	<i>Lotus subbiflorus</i>	2,21 $\pm$ 5,53	3,79 $\pm$ 7,03	<i>Erodium sp.</i>	0,73 $\pm$ 2,94	0,38 $\pm$ 1,13
<i>Paronychia argentea</i>	21,42 $\pm$ 12,46	8,06 $\pm$ 4,75	<i>Malcolmia littorea</i>	3,87 $\pm$ 4,89	0,58 $\pm$ 0,91	<i>Helichrysum italicum</i>	13,46 $\pm$ 9,49	7,26 $\pm$ 8,43
<i>Plantago coronopus</i>	0,62 $\pm$ 2,22		<i>Medicago littoralis</i>	0,1 $\pm$ 0,44		<i>Limoniastrum monopetalum</i>	1,84 $\pm$ 6,96	
<i>Reichardia gaditana</i>		1,04 $\pm$ 2,96	<i>Pancratium maritimum</i>	5,29 $\pm$ 8,33	4,99 $\pm$ 7,07	<i>Lotus creticus</i>	4,56 $\pm$ 6,29	14,56 $\pm$ 14,94
<i>Seseli tortuosom</i>		5,55 $\pm$ 5,95	<i>Paronychia argentea</i>	4,88 $\pm$ 8,29	2,09 $\pm$ 3,27	<i>Lotus subbiflorus</i>	0,87 $\pm$ 1,89	
<i>Suaeda maritima</i>	1,28 $\pm$ 3,33	2,51 $\pm$ 4,23	<i>Plantago coronopus</i>	0,25 $\pm$ 0,68		<i>Malcolmia littorea</i>	3,75 $\pm$ 4,88	2,09 $\pm$ 2,16
<i>Thymus carnosus</i>	0,38 $\pm$ 1,14	7,62 $\pm$ 8,19	<i>Reichardia gaditana</i>	0,88 $\pm$ 1,51	1,53 $\pm$ 1,43	<i>Medicago littoralis</i>		0,89 $\pm$ 1,72
			<i>Senecio gallicus</i>	0,31 $\pm$ 0,37		<i>Pancratium maritimum</i>	1,21 $\pm$ 1,77	0,47 $\pm$ 1,33
			<i>Seseli tortuosom</i>		0,25 $\pm$ 0,81	<i>Paronychia argentea</i>	5,03 $\pm$ 7,19	8,44 $\pm$ 12,33
			<i>Suaeda maritima</i>	12,17 $\pm$ 13,35	4,39 $\pm$ 5,07	<i>Plantago coronopus</i>	3,26 $\pm$ 3,95	8,59 $\pm$ 9,72
			<i>Thymus carnosus</i>	0,08 $\pm$ 0,33	2,53 $\pm$ 4,32	<i>Reichardia gaditana</i>	0,79 $\pm$ 1,03	1,80 $\pm$ 3,13
						<i>Salicornia europaea</i>		0,24 $\pm$ 1,05
						<i>Seseli tortuosom</i>		1,28 $\pm$ 3,00
						<i>Suaeda maritima</i>	1,76 $\pm$ 2,93	0,87 $\pm$ 2,07
						<i>Thymus carnosus</i>	0,49 $\pm$ 1,47	5,76 $\pm$ 5,95