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REPORT

Action A5 of the project Ilhas Barreira

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Report of the Action A5 of the Project LIFE Ilhas Barreira. Report on spatial and resources overlap between seabirds and fisheries, including the main sources of anthropogenic food available for Yellow-legged Gulls

MARE – Marine and Environmental Sciences Centre, University of Coimbra

SPEA

Project coordination
Joana Andrade

Executive team
Jorge M. Pereira, Vitor H. Paiva, Jaime A. Ramos

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Summary

To improve knowledge on distribution of seabirds, especially the Audouin's Gull (*Ichthyaetus audouinii)*, Yellow-legged Gull (*Larus michahellis),* and Balearic Shearwater (*Puffinus mauretanicus)*, in the Algarve region, we performed boat-based surveys, and individual tracking of nesting seabirds on Deserta/ Barreta Island. Main areas used by seabirds, and diet were used to evaluate spatial and trophic overlap with fisheries. The distribution of Yellow-legged gulls and their main feeding sites, especially of anthropogenic origin, were also identified.

The most common species observed during marine surveys were Yellow-legged/Lesser Black-backed gulls (31.7%), followed by Northern gannet (28.6%), Cory's shearwater (11.9%), and Audouin's gull (7.3%). Audouin's gulls were more abundant in coastal waters and in the Southwest of the study area.

A higher fishing effort in the region was registered during spring (April to June), with vessels operating tremmel and gillnets. Overall, seabirds from at least 12 species were observed interacting with artisanal fix-net fisheries. Yellow-legged/Lesser Black-backed gulls were the most abundant species interacting with fishing boats (78.2%), followed by Audouin's gull (4.5%), Northern gannet (1.9%) and Cory's shearwater (1.1%). Yellow-legged gulls and Audouin's gulls overlapped their home range areas with the same areas as purse-seine, set gillnet, and trawler vessels. However, at a finer-scale, purse-seine fisheries were the only fishing gear presented in the core foraging areas of both gull species.

From the 144 fishing trips made in the three years of study, they were only recorded 6 bycatch events. From those events, it was recorded 19 Great Shearwaters, and 3 Northern gannets entangled in trammel nets, and 2 unidentified gulls in gillnets.

Audouin's gulls based their diet on pelagic fish species (41%), namely garfish *(Belone belone)/* Atlantic saury *(Scomberesox saurus;* 29%) and European pilchard (*Sardina pilchardus;* 7%), and on demersal fish (14%), from which seabreams *Diplodus* sp. was the most consumed species (8%). Yellow-legged gulls based their diet on pelagic (20%) and demersal (18%) fish and refuse (22%), with comparably lower prevalence of insects (8%) or Henslow's swimming crab (*Polybius henslowii*; 7%). Higher amounts of landed pelagic and demersal fish by commercial fisheries were related to higher frequency of occurrence of these groups in the diet of both yellow-legged gulls and Audouin's gulls.

Audouin's gulls foraged exclusively at-sea while Yellow-legged gulls foraged both in marine (i.e. open sea) and terrestrial habitats. Tracking of Little Terns suggests that many foraging trips to the lagoon system, intertidal flat and nearby salt pans, and sporadic foraging trips to the ocean, possibly to target marine prey species.

Yellow-legged gulls frequently use habitats associated with anthropogenic activities, namely urban areas, refuse dumps and fishing harbours. The number of Yellow-legged gulls in fishing harbours was more or less constant throughout the year, with a slight increase in August and September, probably related to the income of juveniles that abandoned the colony. The mean number of gulls attending Olhão fishing harbour was significantly higher during the weekdays than on the weekends, probably related to the fishing activity. Most of the food availability for gulls in the fishing harbours comes when fishermen are cleaning the nets and throwing fish scraps on the water or purposely feeding the gulls. Other food sources are related to the presence of fish or other food scattered on the floor, people purposely giving food, and gulls trying to find food in the garbage.

Yellow-legged gulls were also observed feeding in the Sotavento landfill. Overall, the number of immature gulls attending the landfill was higher, except during the breeding period (April to June), where there were more adult Yellow-legged gulls feeding in the landfill. Feeding areas include the locations where the garbage is dumped, with a preferred feeding time during the morning.

Most of the controls of ringed Yellow-legged gulls in Deserta/Barreta and Culatra island were registered in places with greater availability of anthropogenic food sources (fishing harbours, landfills, and urban

areas). These results will be useful for landfill managers, fishermen, and fishing port authorities, in order to define best strategies to reduce anthropogenic food availability to gulls.

Resumo

Para melhorar o conhecimento sobre a distribuição de aves marinhas, especialmente a Gaivota-de-audouin (*Ichthyaetus audouinii*), a Gaivota-de-patas-amarelas (*Larus michahellis*) e a Cagarra-das-baleares (*Puffinus mauretanicus*), na região do Algarve, realizámos levantamentos em barcos e levantamentos individuais. rastreio de aves marinhas nidificantes na ilha Deserta/Barreta. Principais áreas utilizadas pelas aves marinhas e dieta foram utilizadas para avaliar a sobreposição espacial e trófica com a pesca. Foram também identificadas a distribuição das gaivotas-de-patas-amarelas e os seus principais locais de alimentação, sobretudo de origem antropogénica.
As espécies mais comuns observadas durante os levantamentos marinhos foram a gaivota-de-patas-amarelas/gaivota-de-asa-escura (31,7%), seguida pelo alcatraz (28,6%), a cagarra (11,9%) e a gaivota-de-au-douin (7,3%). As gaivotas de Audouin foram mais abundantes nas águas costeiras e no sudoeste da área de estudo.
O maior esforço de pesca na região foi registado durante a primavera (abril a junho), com embarcações a operar redes de emalhar. No geral, foram observadas aves marinhas de pelo menos 12 espécies interagindo com a pesca artesanal com redes fixas. A gaivota-de-patas-amarelas/de-dorso-preto-pequena foi a espécie mais abundante a interagir com os barcos de pesca (78,2%), seguida da gaivota-de-audouin (4,5%), do alcatraz (1,9%) e da cagarra (1,1%). As gaivotas de patas amarelas e as gaivotas de Audouin sobrepuseram as suas áreas de vida às mesmas áreas das redes de cerco, das redes de emalhar e dos navios de arrasto. No entanto, numa escala mais refinada, a pesca com redes de cerco foi a única arte de pesca apresentada nas principais áreas de alimentação de ambas as espécies de gaivotas.
Das 144 saídas de pesca realizadas nos três anos de estudo, apenas foram registados 6 eventos de captura acidental. Desses eventos foram registados 19 cagarros, 3 gansos-patola enredados em tresmalhos e 2 gaivotas não identificadas em redes de emalhar.
As gaivotas de Audouin basearam a sua dieta em espécies de peixes pelágicos (41%), nomeadamente peixe-agulha (*Belone belone*)/ Sauri do Atlântico (*Scomberesox saurus*; 29%) e sardinha europeia (*Sardina pilchardus*; 7%), e em peixes demersais (14%), dos quais os gorazes *Diplodus* sp. foi a espécie mais consumida (8%). As gaivotas de patas amarelas baseavam a sua dieta em peixes pelágicos (20%) e demersais (18%), e em resíduos (22%), com prevalência comparativamente menor de insectos (8%) ou caranguejo nadador de Henslow (Polybius henslowii; 7%). Maiores quantidades de peixes pelágicos e demersais desembarcados pela pesca comercial foram relacionadas com uma maior frequência de ocorrência destes grupos na dieta tanto da gaivota de patas amarelas como da gaivota de Audouin.
As gaivotas de Audouin alimentam-se exclusivamente no mar, enquanto as gaivotas de patas amarelas alimentam-se tanto em habitats marinhos (ou seja, mar aberto) como terrestres. O rastreamento de andorinhas-do-mar sugere que muitas viagens de forrageamento para o sistema lagunar, planícies intertidais e salinas próximas, e viagens esporádicas de forrageamento para o oceano, possivelmente para atingir espécies de presas marinhas.
As gaivotas de patas amarelas utilizam frequentemente habitats associados a atividades antrópicas, nomeadamente áreas urbanas, lixeiras e portos de pesca. O número de gaivotas-de-patas-amarelas nos portos de pesca manteve-se mais ou menos constante ao longo do ano, com um ligeiro aumento em Agosto e Setembro, provavelmente relacionado com o rendimento dos juvenis que abandonaram a colónia. O número médio de gaivotas que frequentaram o porto de pesca de Olhão foi significativamente maior durante os dias de semana do que nos fins de semana, provavelmente relacionado com a actividade piscatória. A maior parte da disponibilidade de alimentos para as gaivotas nos portos de pesca ocorre quando os pescadores estão limpando as redes e jogando

restos de peixe na água ou alimentando as gaivotas propositalmente. Outras fontes de alimento estão relacionadas à presença de peixes ou outros alimentos espalhados pelo chão, pessoas dando comida propositalmente e gaivotas tentando encontrar comida no lixo.
Também foram observadas gaivotas de patas amarelas a alimentar-se no aterro do Sotavento. No geral, o número de gaivotas imaturas que frequentaram o aterro foi maior, excepto durante o período de reprodução (Abril a Junho), onde havia mais gaivotas-de-patas-amarelas adultas a alimentar-se no aterro. As áreas de alimentação incluem os locais onde o lixo é despejado, com horário preferencial de alimentação durante a manhã.
A maior parte dos controlos de gaivota-de-patas-amarelas-aneladas nas ilhas Deserta/Barreta e Culatra foram registados em locais com maior disponibilidade de fontes alimentares antropogénicas (portos de pesca, aterros e zonas urbanas). Estes resultados serão úteis para gestores de aterros, pescadores e autoridades portuárias de pesca, a fim de definir as melhores estratégias para reduzir a disponibilidade de alimentos antropogénicos para as gaivotas.

1 | Introduction

1.1 Seabird dependence of Anthropogenic resources

Predictable anthropogenic food subsidies (PAFS) have traditionally been provided to animals, and as a result, many populations and ecosystems as we know them now have been impacted. PAFS boost individual fitness, leading to population expansions of opportunistic species such as gulls (Oro et al. 2013). However, studies have shown that PAFS might decrease population variability (Oro et al. 2013), increase resilience of opportunistic species (Matos et al. 2018) and reduce community diversity (Cortés-Avizanda et al. 2012).
Since ancient times, there has been interaction between seabirds and fisheries, often to the benefit of both. For instance, seabirds gave fishermen visual clues of fish aggregations and feed on PAFS generated by fishing activities. Yet, fisheries and seabirds may also compete for the same resources. As a result, vulnerable seabird populations may be threatened. These interactions can also increase seabird mortality through unintentional bycatch and declining fishing efficiency (Bot et al. 2018).
Recent environmental laws, like the regulation of management in dumps or the ban of fishing discards, should have mensurable effects on scavenging populations of gulls (Carmona et al. 2021). Thus, comparison of subsidised and non-subsidized ecosystems can help predict changes in wildlife populations and associated ecosystem services provided by those species (Oro et al. 2013). Yet, few studies have tested empirically how the lack of PAFs, such as landfill closure or a discard ban, might affect individuals' foraging strategies and dietary preferences with consequences at a population level (Bicknell et al. 2013, Fondo et al. 2015).

1.2 Objectives

The aim of this Action 5 deliverable "Spatial and resources overlap between seabirds and fisheries, including main sources of anthropogenic food available for Yellow-legged Gulls" was to collate and analyse in combination the information gathered during the project on (1) seabirds' (action A5) and (2) fisheries (action A6) distributions in order to evaluate spatio-temporal overlap in space and resource use and quantify the influence of anthropogenic resources availability on the diet and distribution of gulls (action C8).

2 | Spatial overlap between seabirds and fisheries

2.1 Seabirds distribution off Algarve

2.1.1 Methods

Counts of seabirds at sea were made between January 2020 and January 2022, from Albufeira to Vila Real de Santo António up to 20 nautical miles off the coastline (Fig. 1). Monthly at-sea surveys were carried out in two or three consecutive days along a predefined transect and following the European Seabirds At-Sea (ESAS) methodology (Camphuysen and Garthe, 2004). Briefly, observations were collected by trained observers, in units of linear transects, described as a continuous 90° scan with concurrent 300 m wide strip transect, and grouped into 5 min period (Tasker *et al.*, 1984). Here, we only considered seabirds in contact with water and within the 300 m strip transect band around the boat for further analysis. A summary of the total number and percentage of seabirds observed per month is given in Table 1. Yellow-legged and Lesser Black-backed gulls were grouped in a single class (hereafter Yellow-legged/ Lesser Black-backed gulls) due to the difficulty in identifying each species separately by the trained observers at-sea.

2.1.2 Results and Discussion

Overall, 18.359 seabirds were counted from ESAS surveys, of which 13.799 seabirds from at least 25 species were counted within 300 m around the boat and were in contact with water (Table 1). Yellow-legged/ Lesser Black-backed gulls (*Larus fuscus*) were the most common species observed in our study area (34.8%), followed by Northern gannet (*Morus bassanus*; 28.9%), Cory's shearwater (*Calonectris borealis*; 11.3%) and Audouin's gull (*Ichthyaetus audouinii;* 6.6%) (Table 1). Whenever possible the taxonomic identification was made to the level of genus, which accounted for 8.8% of the total counted seabirds. Overall, Yellow-legged/Lesser Black-backed gulls and Northern gannets were observed throughout the year (Fig. 2) and spanning the entire range of the study area in both coastal and pelagic waters (Fig. 3). Interestingly, Yellow-legged/Lesser Black-backed gulls were mainly observed at-sea during the post-breeding (September-December), than during the breeding period (April-August) (Fig. 3). Northern gannets were mainly observed during the post-breeding period (October-December), whereas Cory's shearwaters (May-October) and Audouin's gulls (April-August) were mostly observed during the breeding period, respectively (Fig. 3). Cory's shearwaters were more abundant in pelagic areas, whereas Audouin's gulls were more abundant in coastal waters and in the Southwest of the study area (Fig. 2).

Table 1 | Total number and percentage of seabirds observed per month in the European Seabirds At-Sea (ESAS) between January 2020 and January 2022 in the study area (see Fig. 2.1).

Species	Winter			Spring			Summer			Autumn			N	%
	Dec	Jan	Fev	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov		
Larus fuscus/ Larus michahellis	838	0	24	134	162	87	167	183	429	835	861	1075	4795	34.75
Morus bassanus	710	0	127	544	43	263	195	67	70	251	575	1140	3985	28.88
Calonectris borealis	0	0	0	0	0	2	154	236	481	546	65	77	1561	11.31
Larus sp.	0	0	41	387	163	293	1	131	17	4	56	63	1156	8.38
Ichthyaetus audouinii	8	0	20	20	256	228	207	100	65	5	0	0	909	6.59
Hydrobates pelagicus	14	0	0	5	0	8	13	4	3	152	63	115	377	2.73
Stercorarius skua	33	0	47	42	7	8	12	56	1	38	42	82	368	2.67
Phalacrocorax carbo	8	0	11	90	1	0	0	0	1	0	0	20	131	0.95
Puffinus mauretanicus	12	0	0	0	1	33	12	9	5	1	6	20	99	0.72
Ichthyaetus melanocephalus	12	0	4	0	0	0	0	0	0	2	17	40	75	0.54
Ardenna grisea	0	0	0	1	0	37	7	3	0	1	2	5	56	0.41
Hydrobates sp.	0	0	5	1	0	2	3	2	10	10	1	14	48	0.35
Melanitta nigra	0	0	0	32	0	1	0	0	0	0	4	4	41	0.30
Thalasseus sandvicensis	0	0	0	6	0	10	4	0	0	2	2	7	31	0.22
Hydrobates castro	1	0	1	0	0	1	7	3	6	1	2	2	24	0.17
Sterna hirundo	0	0	0	1	0	0	5	2	7	1	2	2	20	0.14
Alca torda	1	0	0	15	0	0	0	0	0	0	0	3	19	0.14
Oceanites oceanicus	0	0	0	0	0	0	0	3	10	0	1	1	15	0.11
Chroicocephalus ridibundus	5	0	6	1	1	0	0	0	0	0	0	2	15	0.11
Sternula albifrons	0	0	0	0	0	0	6	9	0	0	0	0	15	0.11
Chlidonias niger	0	0	0	0	0	0	5	0	3	5	0	0	13	0.09
Ardenna gravis	0	0	0	0	0	0	0	1	5	6	0	0	12	0.09
Puffinus puffinus	0	0	0	0	0	0	0	0	1	0	4	4	9	0.07
Rissa tridactyla	1	0	0	0	0	0	0	0	0	0	1	4	6	0.04
Fratercula arctica	0	0	0	4	0	1	0	0	0	0	0	0	5	0.04
Sterna sp.	0	0	0	0	0	0	0	1	0	3	0	0	4	0.03
Phalaropus fulicarius	3	0	0	0	0	0	0	0	0	0	0	0	3	0.02
Phalaropus lobatus	0	0	0	0	0	0	0	0	1	0	1	1	3	0.02
Stercorarius parasiticus	0	0	0	0	0	0	0	0	1	1	0	0	2	0.01
Stercorarius sp.	0	0	0	0	1	0	0	0	0	0	0	0	1	0.00
Onychoprion fuscatus	0	0	0	0	0	1	0	0	0	0	0	0	1	0.00
Total	1646	0	286	1283	635	975	798	810	1116	1864	1705	2681	13799	100

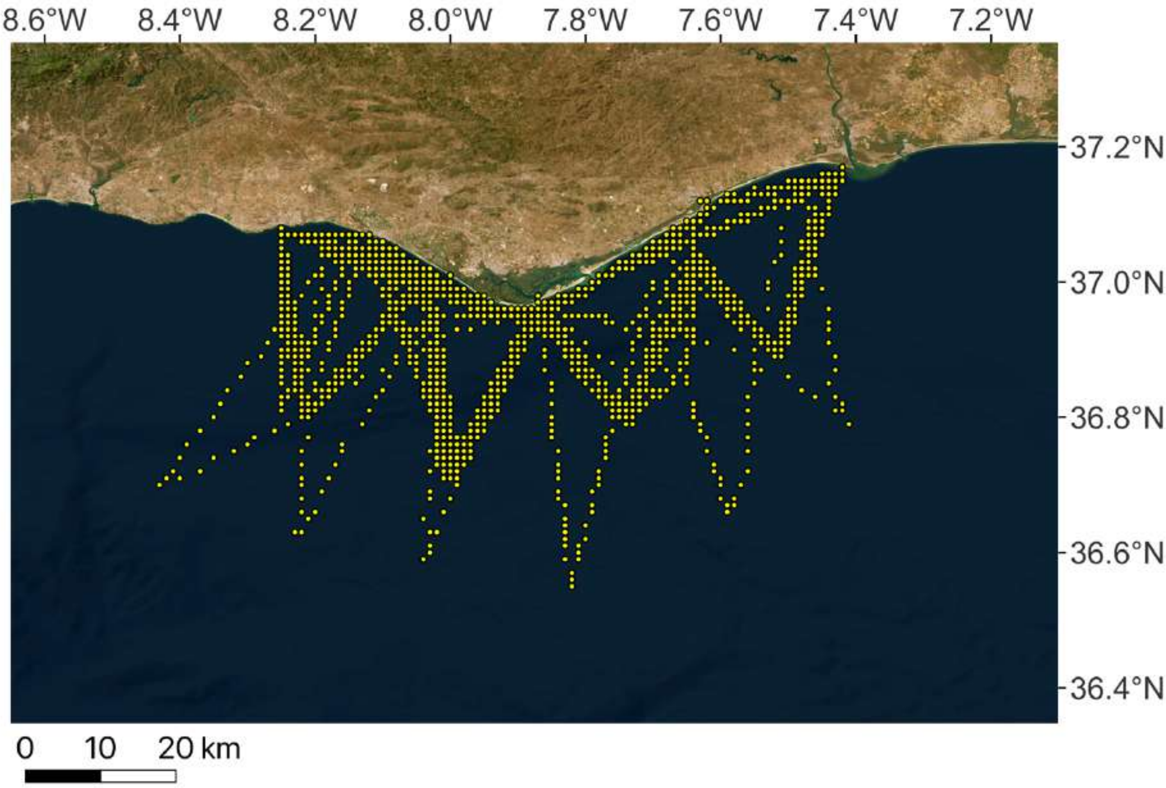

Figure 1 | Map showing the overall sampling effort between January 2020 and January 2022. At-sea shipboard surveys were conducted between Albufeira to Vila Real de Santo António following a European Seabirds At-Sea (ESAS) methodology.

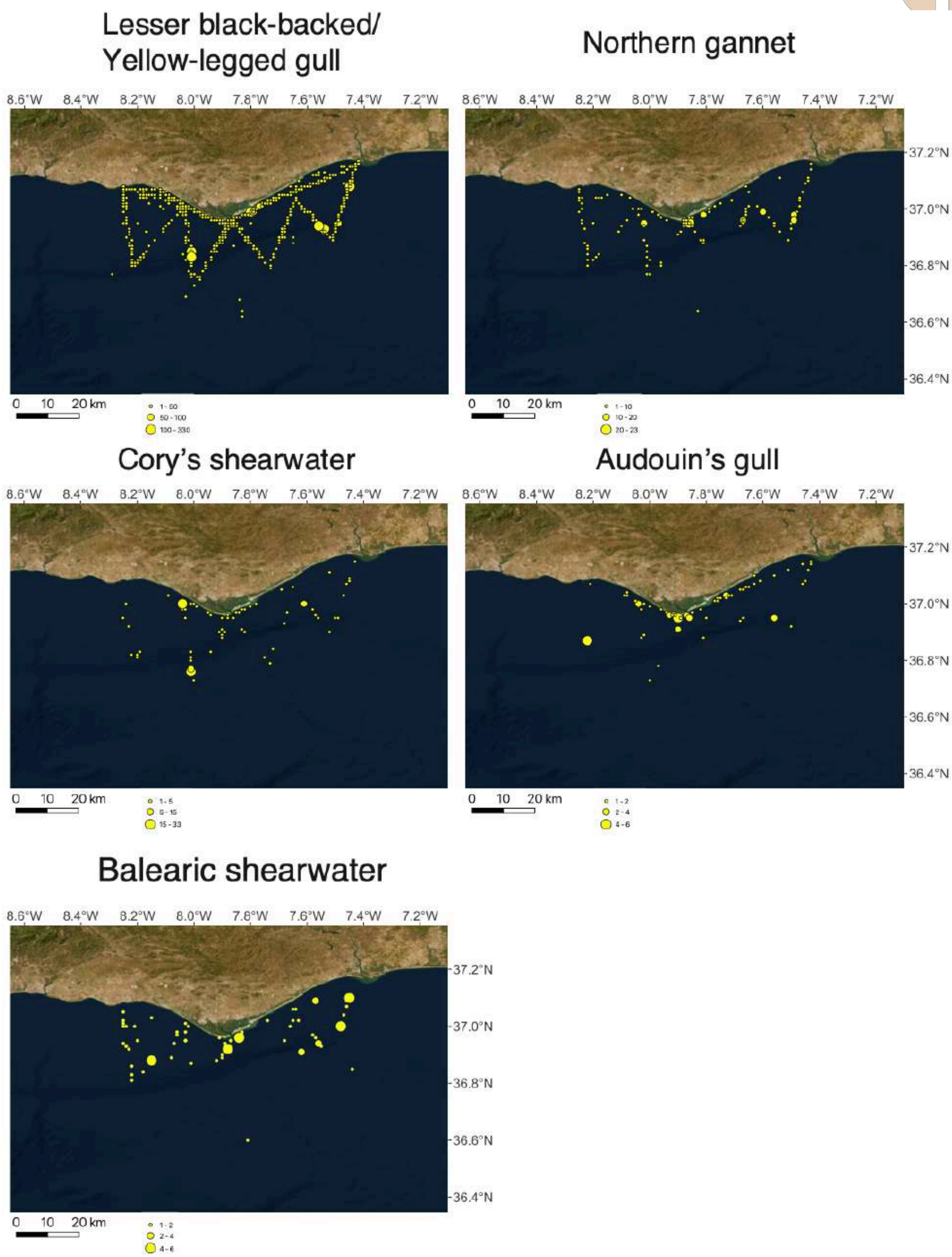

Figure 2 | At-sea distribution and abundance of the main observed species in the study area (Yellow-legged *Larus michahellis*/ Lesser Black-backed gull *Larus fuscus*, Northern gannet *Morus bassanus*, Cory's shearwater *Calonectris borealis* and Audouin's gull *Ichthyaetus audouinii*) and the critically endangered Balearic shearwater *(Puffinus mauretanicus*).

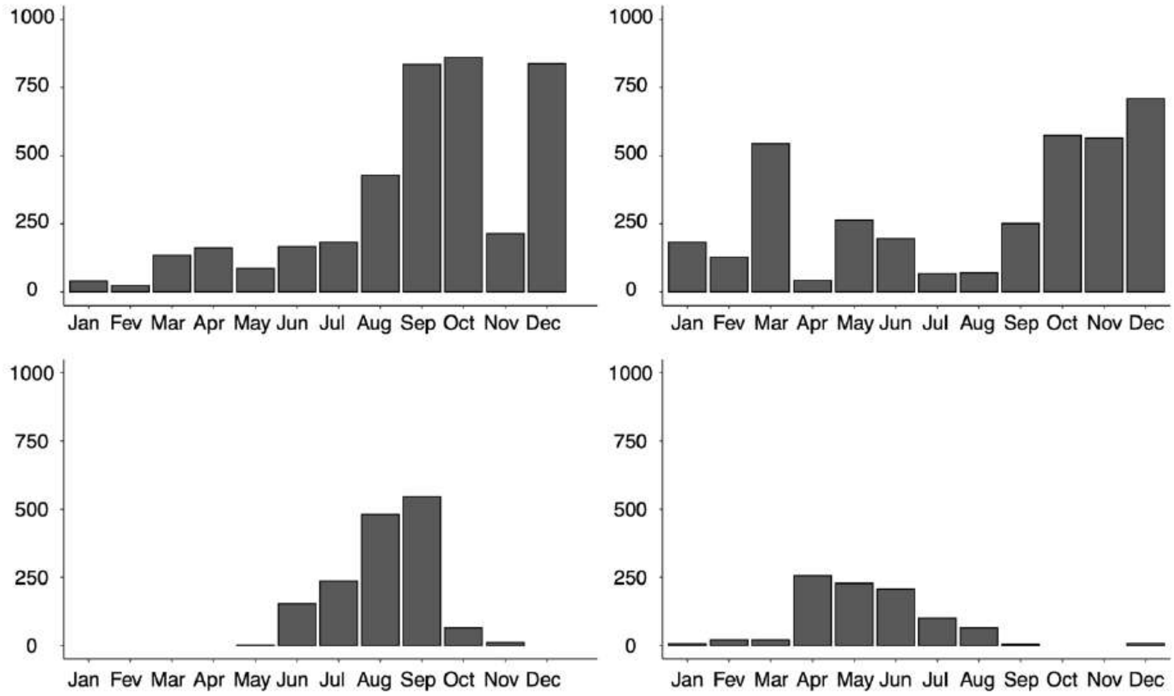

Figure 3 | Monthly abundance of the main observed species in the study area (Yellow-legged *Larus michahellis*/ Lesser Black-backed gull *Larus fuscus*, Northern gannet *Morus bassanus*, Cory's shearwater *Calonectris borealis* and Audouin's gull *Ichthyaetus audouinii*).

2.2 Spatio-temporal distribution of fishing effort

2.2.1 Methods

To access fisheries distribution, surveys to fishing captains were carried out between December 2019 and December 2021 by the team from the Center for Marine Sciences of the University of Algarve (UAlg/CCMAR). The surveys took place quarterly (January-March, April-June, July-September, and October-December), with the target fleet including vessels operating gillnets, trammel, and purse seines, from Cabanas de Tavira, Culatra, Fuseta, Monte Gordo, Olhão, Quarteira and Tavira. The fishing areas of each vessel were identified based on the information provided by fishing captains, namely the east, west, and south limits. The fishing effort was also provided in the number of fishing events/ 3 months. In total, 737 surveys were carried out in 112 vessels operating gillnets, 119 operating tremmel, and 20 purse seiners.
The rasterization of the fishing effort was defined within the scope of the project Life MarPro (LIFE09 NAT/PT/000038), with the grid size 0.04x0.04 degrees (about 4x4 km) and cut to the west limit at the parallel of Albufeira, the east limit at the parallel of Vila Real de Santo António and to the south for a distance of about 20 miles coastline, where each square represented the sum of the fishing effort of the total number of vessels operating a given fishing gear, in a given quarter.

2.2.2 Results and Discussion

Vessels operating tremmel and gillnets have a greater number of fishing events in the region (Fig. x). The different fishing gear had similar fishing areas, mainly occupying areas close to coast, especially in the south of Deserta/Barreta island (Fig. 4).
A higher fishing effort was registered during spring (April to June) in all gears considered, with fishing areas remaining practically the same between seasons (Appendix A). A high fishing effort during spring, coincides with the breeding season of the Audouin gull, the Yellow legged-gull, and the Little tern, which can increase the probability of bycatch in fishing gears or competition for the same resources.

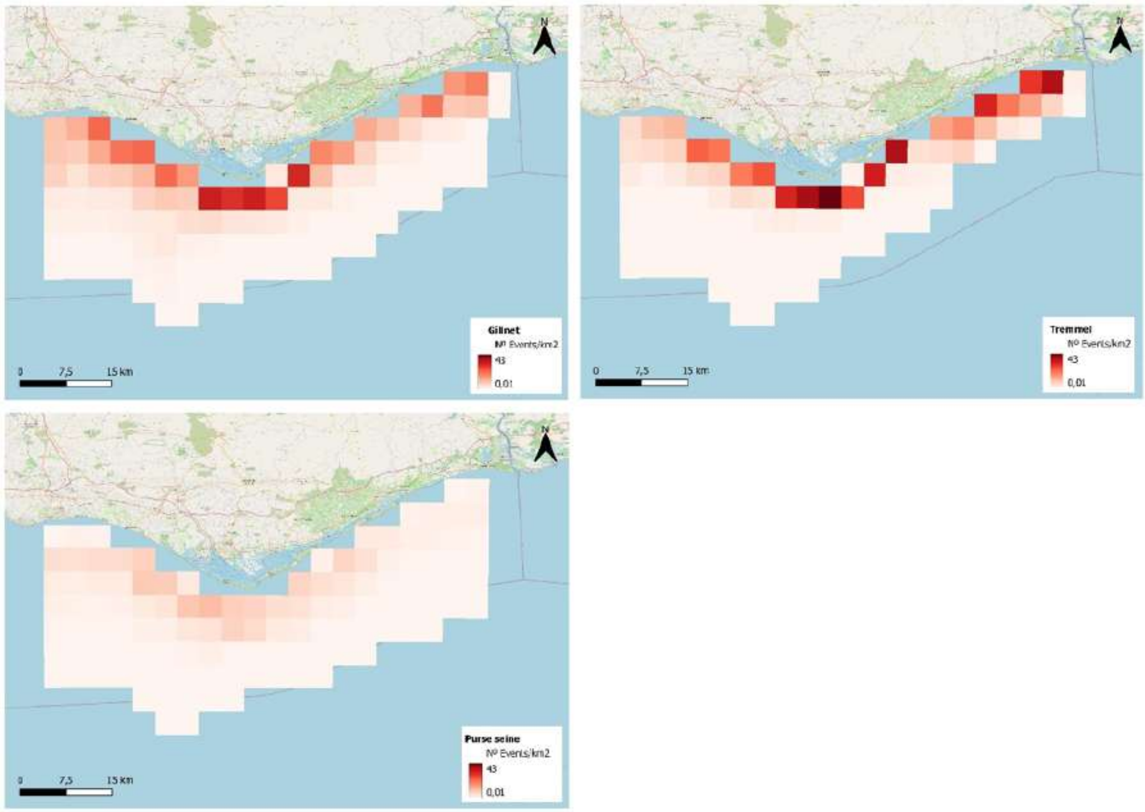

Figure 4 - Maps of fishing effort distribution for gillnets (top left), trammel nets (top right) and purse-seines (bottom).

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2.3 Spatial overlap between gulls and industrial fisheries

2.3.1 Methods

Raster files detailing the daily distribution of fishing effort (in hours) were downloaded from Global Fishing Watch (https://globalfishingwatch.org/) at a 0.01° grid cell resolution (approx. 1 km) for every day between April and November (2012−2020). Global Fishing Watch is an open access global database that uses remote sensing and convolutional neural networks to classify the activity of vessels larger than 15 m as fishing or not fishing (Kroodsma et al. 2018). Here, we computed the average fishing effort between April and November for the 2012-2020 period as the overall representation of the fishing effort in the study area. Secondly, we computed the 50% (core foraging areas) and 95% (home-range areas) Kernel Utilisation Distributions (KUDs) for each species, within different years and breeding phases. KUDs were performed using the '*adehabitatHR*' R package (Calenge 2006). Lastly, to quantify spatial overlap of fisheries with tracked gulls, we extracted the cumulative fishing hours within 50% and 95% KUD for each species, within different years and breeding phases.

2.3.2 Results and Discussion

During incubation, both Yellow-legged and Audouin's gulls tracked with GPS-loggers repeatedly used the same areas as industrial fishing vessels over the study years (Fig. 5). Individuals from both species overlapped their home range areas (95% KUDs) with the same areas as purse-seine (PS), set gillnet (SG) and trawler (TR) vessels. However, at a finer-scale, purse-seine fisheries were the only fishing gear presented in the core foraging areas (50% KUDs) of both gull species (Fig. 5). Despite the low number of fishing hours occurring within the home-range areas of Audouin's gull, longline fishing vessels did not occur within those from Yellow-legged gulls (Fig. 5). This differential overlap with longline fisheries raises some concerns for the conservation of Audouin's gulls, since longline fishing vessels represent one of the most lethal fishing gears to seabirds worldwide.

Similar to Yellow-legged gulls tracked with GPS-loggers, those tracked with GPS-GSM loggers also did not use the same areas as longline fisheries in any breeding phase, but rather used the same areas as purse-seine fisheries in their core foraging areas along the annual cycle and as trawler fisheries during the post-breeding period (Fig. 6). In relation to Audouin's gulls, GPS-GSM tagged birds used the same areas as purse-seines, set gillnets and trawlers during the incubation and chick-rearing periods (Fig. 6). However, during the post- breeding period Audouin's gulls decreased the use of the same areas as purse-seines fishing vessels, continued to use the same areas as trawlers and started to use the areas where longline fishing vessels usually operate (Fig. 6).

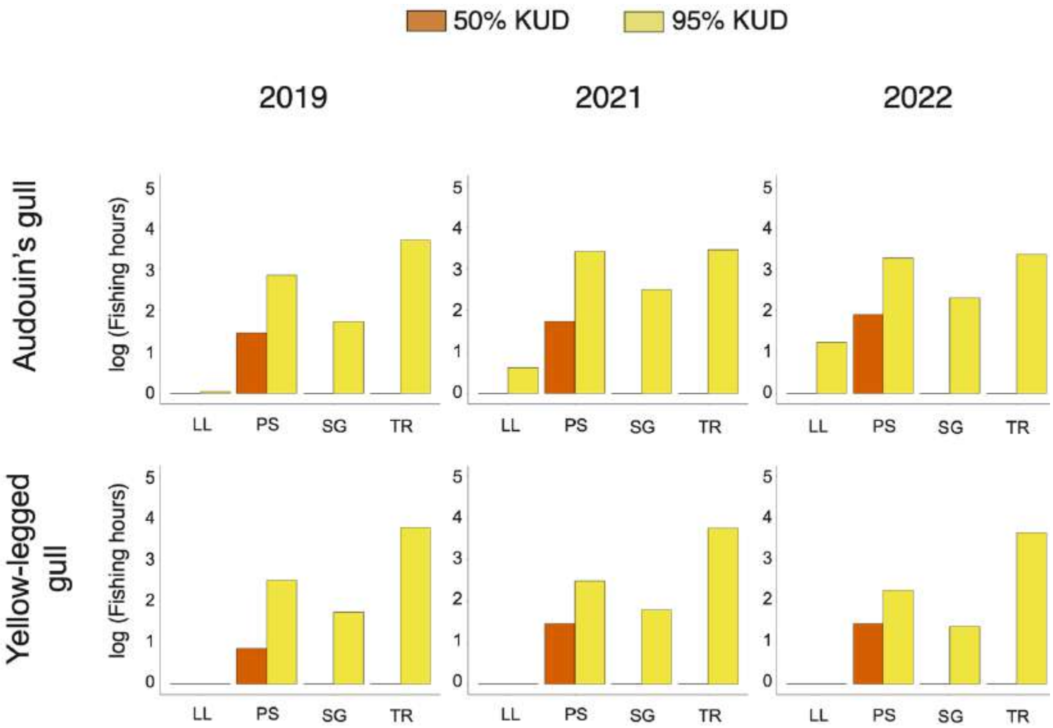

Figure 5 | Barplots showing the cumulative fishing hours (log-transformed) within the Kernel Utilisation Distributions (KUDs) 50% and 95% areas of Yellow-legged gulls (*Larus michahellis*) and Audouin (*Ichthyaetus audouinii*) gulls breeding at Deserta Island during the incubation in 2019, 2021 and 2022. Longlines (LL), Purse-seines (PS), Set Gillnets (SG) and Trawlers (TR).

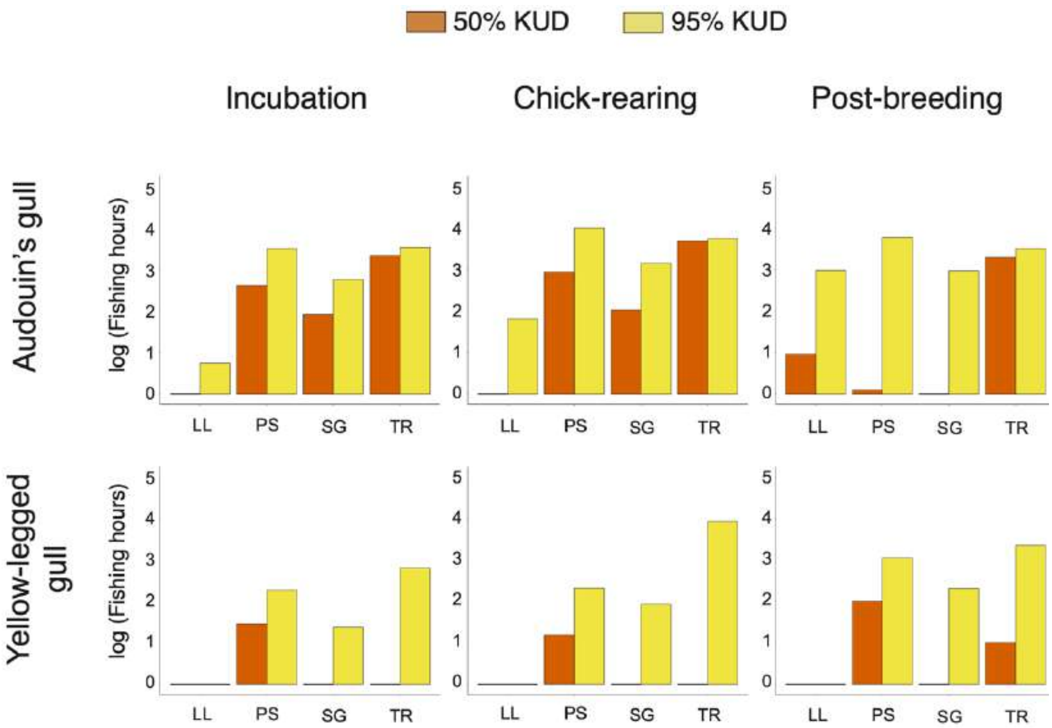

Figure 6 | Barplots showing the cumulative fishing hours (log-transformed) within the Kernel Utilisation Distributions (KUDs) 50% and 95% areas of Yellow-legged gulls (*Larus michahellis*) and Audouin (*Ichthyaetus audouinii*) gulls breeding at Deserta Island during incubation (April-May), chick-rearing (June-August) and post-breeding (September-November) in 2022. Longlines (LL), Purse-seines (PS), Set Gillnets (SG) and Trawlers (TR).

2.4 Seabird-fisheries interactions

2.4.1 Methods

Data on seabird-fishery interactions was obtained from four artisanal Portuguese fixed-net fishing vessels (N= 144 trips and N= 333 sets) during three consecutive years (from March 2020 to June 2022). During the winter months (December to February), the observation effort was reduced or nearly absent because of frequent bad weather conditions and the temporary closure of fishing activities due to COVID-19 restrictions (Table 2). The sampled vessels' overall length ranged from 7.1 and 13.5 m, for a gross tonnage (GT) of 3.2 T to 17 T, an engine power of 12 kW to 74 kW and a crew member of 2 - 6 fishermens. These fishing vessels departed mainly from Olhão and rarely from Quarteira (Fig. 7). All four vessels used traditional monofilament bottom-set gillnets - or rarely trammel nets - with mesh sizes between 60 mm to 220 mm. Skippers went out for daily nearshore trips of a few hours (8.2 h ± 1.3 h) and targeting mostly demersal fish such as European hake (*Merluccius merluccius*), common monkfish (*Lophius piscatorius*), thickback sole (*Microchirus variegatus*), Nursehound (*Scyliorhinus stellaris*) and *Pagellus* sp, accounting for approximately 60.33% of the total fishery catches (Table 3). Fishing trips never exceeded 14 h and consisted of hauling the net fleets set in the previous day. Fishing vessels typically set one net fleet per fishing trip (1.1 ± 0.5 fishing events per trip), with a net depth spanning between 11 m to 243 m (111.5 ± 60.5 m).

Table 2 | Total number and percentage of seabirds observed interacting with artisanal fixed-net fishing vessels per month between March 2020 and June 2022 in the study area (Fig. 3.1).

Trips/ Seabird species	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	N	%	Birds/ trip
N trips (N fishing events)	2 (5)	13 (29)	22 (44)	18 (36)	29 (71)	21 (54)	13 (32)	17 (45)	7 (13)	2 (4)	144 (333)	-	-
Black-backed/ Yellow-legged gu	405	1318	1651	975	1944	2092	2276	1940	1345	20	13966	78.23	96.99
Unidentified gull	133	103	680	27	121	215	19	690	565	1	2554	14.31	17.74
Audouin's gull	0	134	237	123	130	4	13	0	0	0	641	3.59	4.45
Northern gannet	34	0	8	5	5	1	5	154	56	6	274	1.53	1.90
Cory's shearwater	0	0	0	24	66	61	0	1	0	0	152	0.85	1.06
Unidentified shearwater	0	0	1	1	0	0	0	113	0	0	115	0.65	0.80
Great skua	4	2	1	1	2	1	3	14	15	0	43	0.24	0.30
European storm-petrel	0	2	4	0	1	2	9	17	0	0	35	0.20	0.24
Balearic sheatwater	0	0	1	14	8	3	1	2	0	0	29	0.16	0.20
Wilson's storm-petrel	0	12	2	0	0	0	0	0	0	0	14	0.08	0.10
Sandwich tern	0	0	6	0	2	0	2	0	0	0	10	0.06	0.07
Black tern	0	0	0	7	0	0	0	0	0	0	7	0.04	0.05
Great shearwater	0	0	0	0	0	0	0	2	1	2	5	0.03	0.03
Mediterranean gull	0	0	0	0	0	0	0	3	0	0	3	0.02	0.02
Common tern	0	0	1	0	0	1	1	0	0	0	3	0.02	0.02
Unidentified species	0	0	1	0	0	0	0	0	0	0	1	0.01	0.01
Total	578	1571	2592	1177	2279	2380	2329	2936	1982	29	17853	100.00	123.98

Table 3 | Main fishery catch in the monitored fisheries from Olhão and Quarteira fishing fleet. Percentages were calculated by each catch and by species. Species are ordered by decreasing total catch.

Species	Percentages by catch (%)			Percentages by species (%)	
	Total	Retained	Discarded	Retained	Discarded
Merluccius merluccius	19.81	18.24	24.84	100.00	0.00
Lophius piscatorius	13.71	15.95	6.53	60.00	40.00
Microchirus variegatus	11.99	15.35	1.21	100.00	0.00
Scyliorhinus stellaris	5.14	5.66	3.44	50.00	50.00
Pagellus acarne	5.09	6.54	0.45	100.00	0.00
Pagellus erythrinus	4.59	5.90	0.39	2.38	97.62
Sarpa salpa	3.41	0.01	14.31	100.00	0.00
Scyliorhinus canicula	3.39	3.19	0.50	100.00	0.00
Trachurus trachurus	3.00	3.93	0.00	100.00	0.00
Scomber scombrus	2.45	0.61	8.33	89.45	10.55
Holothuriidae	2.28	0.01	9.53	100.00	0.00
Mullus surmuletus	2.19	2.71	0.55	0.00	100.00
Scorpaena sp.	2.13	0.40	7.66	99.27	0.73
Scomber colias	1.83	2.40	0.00	91.72	8.28
Diplodus sp.	1.58	1.66	1.31	66.67	33.33
Solea solea	1.50	1.28	0.30	100.00	0.00
Diplodus vulgaris	0.01	1.13	0.63	77.42	22.58
Charonia lampas	0.97	1.27	0.03	83.33	16.67
Lophius budegassa	0.97	1.22	0.18	66.67	33.33

Counts of seabirds in the vicinity of vessels were made by trained observers every 15 min during each fishing trip, focussing on the time the vessels engaged on a fishing event (setting *vs*. hauling). Where accurate identification to species level was not possible, identifications to higher-order taxonomic groups (family) were made. Seabird counts were not done during night due to poor visibility. Directional flights and distances >100 m were removed from the analysis to only account for seabirds that were interacting with fishing vessels during active fishing sets. Seabird age classes (adult *vs*. immature) were also registered whenever possible. Additional data which could affect the abundance of seabirds in the vicinity of fishing vessels was also collected for each trip. Specifically, for each trip observers recorded the fishing method used (gillnets *vs*. trammel nets), the fishing event (setting *vs*. hauling) and the total number of fish caught during hauling (hereafter fishery catch). Fishery catch was divided into retained (if retained on board) and discarded (if returned to the sea after being hauled aboard). Lastly, observers also registered the number of seabird bycatch in each fishing event and during each trip. Scatterplots and correlation coefficients with *P-values* were performed using the '*ggpubr*' R package.

2.4.2 Results and Discussion

Overall, seabirds attended artisanal fix-net fisheries in 99.2% of 144 fishing trips and 75.1% of 333 fishing sets, accounting for 17.853 seabirds from at least 12 species (Table 8). Yellow-legged/ Lesser Black-backed gulls were the most abundant species interacting with fishing boats (78.2%), followed by Audouin's gull (4.5%), Northern gannet (1.9%) and Cory's shearwater (1.1%). Overall, *Larus* spp. accounted for 92.5% of the total species interacting with fishing boats. The number of seabirds for the species that interact more with fishing vessels varied considerably throughout the year. While Audouin's gulls interacted with fishing vessels solely during the breeding period, Northern gannets interacted with fishing vessels almost exclusively during the post-breeding period (mainly during December) (Fig. 8). Cory's shearwaters interacted more with fishing vessels during the breeding period (mainly during the chick-rearing), but also during part of the non-breeding period (January-February) (Fig. 8). Yellow-legged/ Lesser Black-backed gulls interacted with fishing vessels during all months of the year, excepting during the winter months (Fig. 8), where fishing activity is usually low due to the bad weather. 82.6% of the total number of seabirds recorded with known age were Yellow-legged/ Lesser Black-backed gulls, with adult gulls interacting more with fishing vessels (58.96%) when compared to immatures (41.04%). *Larus* spp. accounted for 10.4% of the number of seabirds with known age. The number of seabirds for the species that interact more with fishing vessels were considerably higher during hauling operations and when fishing vessels were operating gillnets (Fig. 9). The number of Yellow-legged/ Lesser Black-backed and Audouin's gulls were positively correlated with the total number of fishery catches (Fig. 10). The number of seabirds of the aforementioned species interacting with fishing vessels was not correlated with fishery discards nor the fishery retained inside the fishing boat. From the 144 fishing trips made in the three years of study, they were only recorded 6 bycatch events. From those events, it was only recorded 24 individual seabirds entangled in trammel nets and rarely in gillnets (Fig. 11).

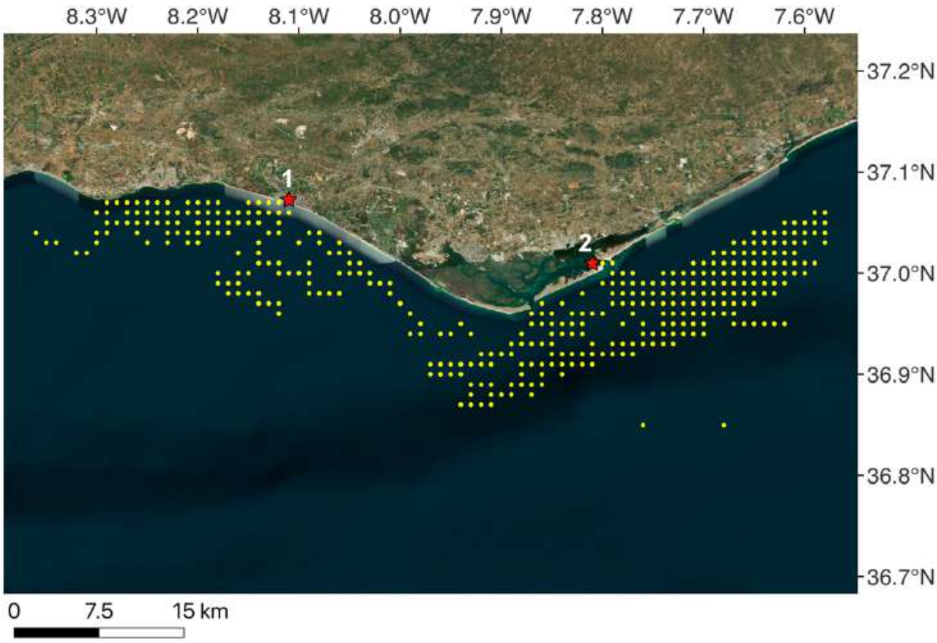

Figure 7 | Map showing the overall locations of observed seabirds interacting with artisanal fixed-net fishing vessels between March 2020 and June 2022. Fishing vessels departed from (1) Quarteira and (2) Olhão (red stars).

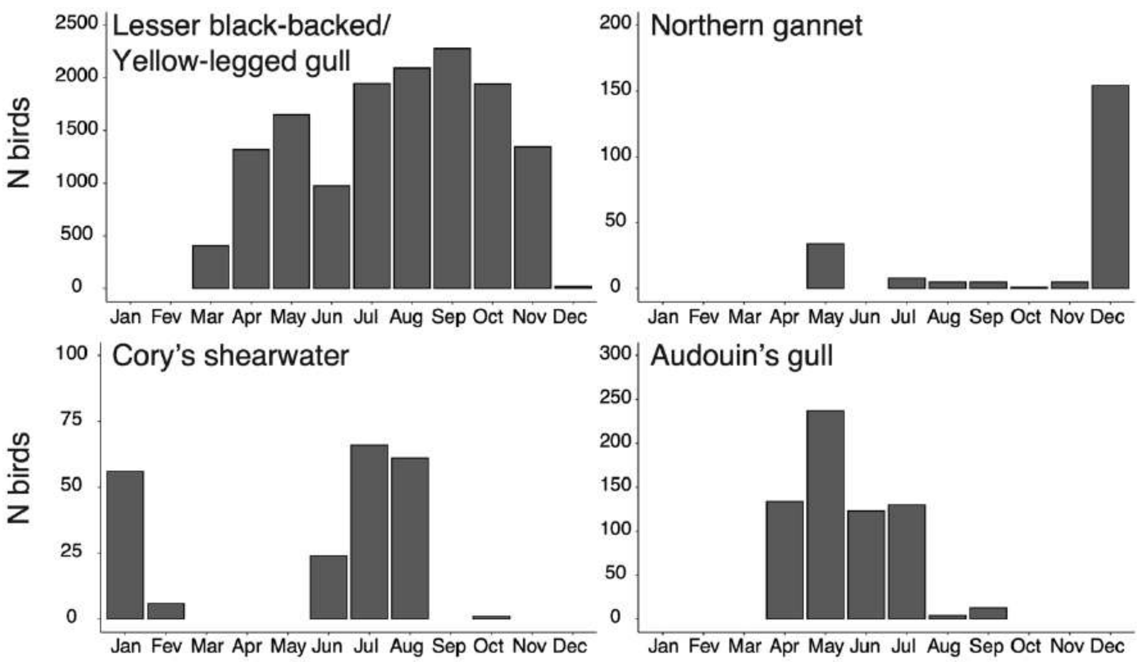

Figure 8 | Monthly abundance of the species interacting more with artisanal fixed-net fishing vessels in our study area (Yellow-legged *Larus michahellis*/ Lesser Black-backed gull *Larus fuscus*, Northern gannet *Morus bassanus*, Cory's shearwater *Calonectris borealis* and Audouin's gull *Ichthyaetus audouinii*).

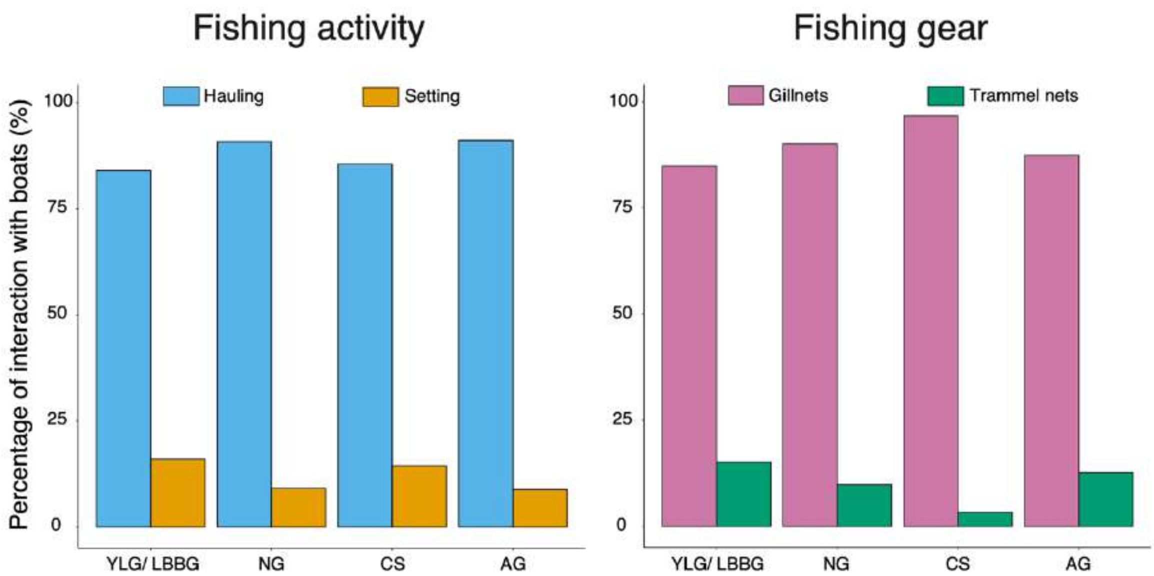

Figure 9 | Barplots showing the percentage of Yellow-legged *Larus michahellis*/ Lesser Black-backed gull *Larus fuscus* (YLG/LBBG), Northern gannet *Morus bassanus* (NG), Cory's shearwater *Calonectris borealis* (CS) and Audouin's gull *Ichthyaetus audouinii* (AG) interacting with artisanal fixed-net fishing vessels between March 2020 and June 2022 in the study area, in relation to fishing activity (hauling *vs*. setting) and fishing gear (gillnets *vs*. trammel nets).

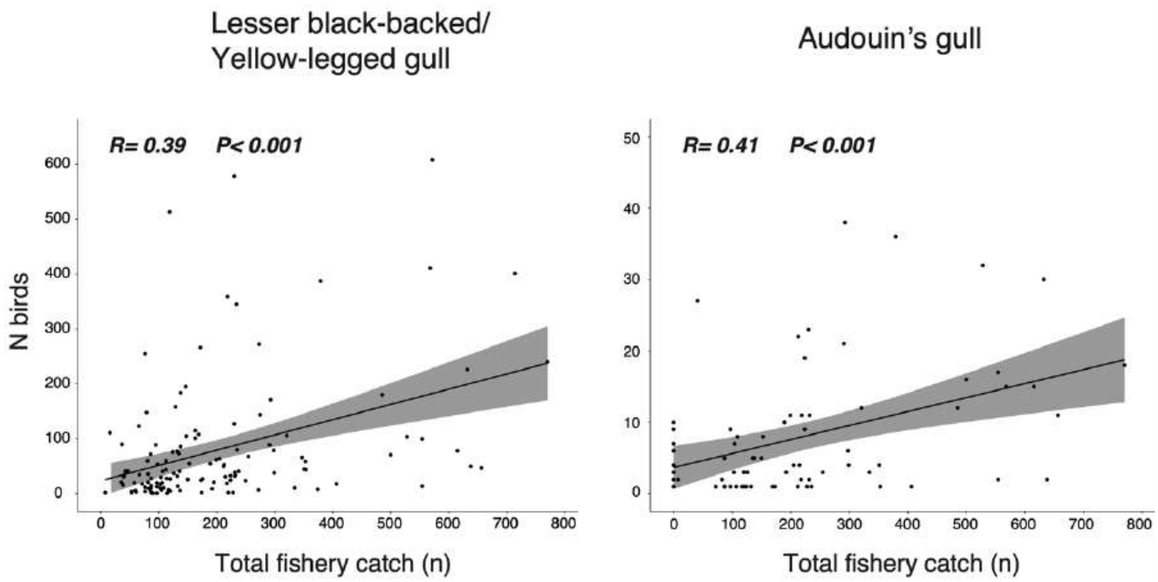

Figure 10 | Scatterplots showing the positive relation between the number of Yellow-legged *Larus michahellis*/ Lesser Black-backed gull *Larus fuscus* and Audouin's gull *Ichthyaetus audouinii*) observed interaction with artisanal fisex-net fishing vessels and the total amount of fishery catch.

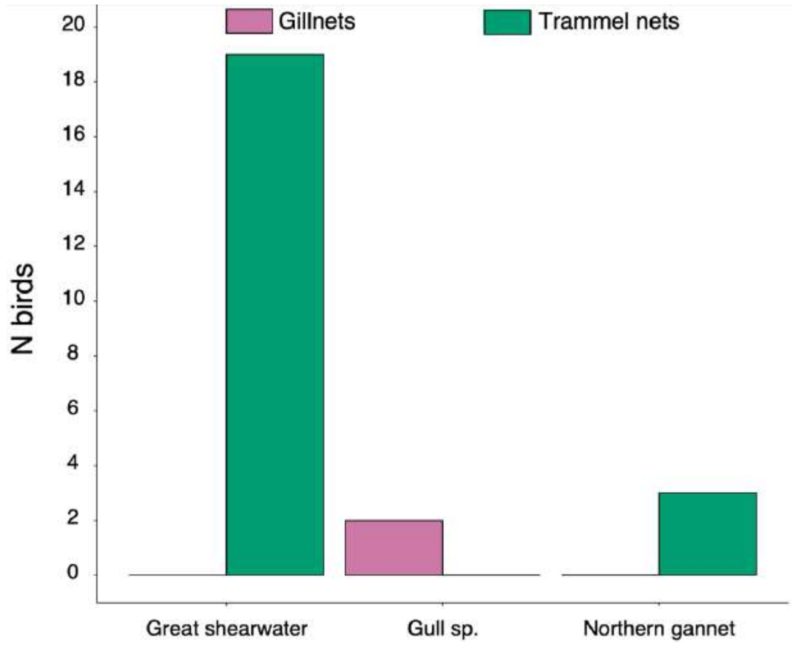

Figure 11 | Barplots showing the cumulative bycatch observed in each gear type (gillnets *vs*. trammel nets) for Great shearwaters (*Ardenna gravis*), unidentified gull species (Gull sp.) and Northern gannet (*Morus bassanus*).

3 | Seabird diet and fishery landings

3.1 Methods

Fishery landings from the fishing ports of Quarteira, Olhão and Fuseta, the closest ports from the breeding colony of Audouin's and yellow-legged gulls, were provided by 'DGRM - Direcção Geral de Recursos Naturais, Segurança e Serviços Marítimos' (https://www.dgrm.mm.gov.pt). Data was limited to the months of April-May of 2019-2022, to match the information collected from the diet of both gull species during their breeding period and at their breeding colony, on Deserta Island. The data includes the number of fish landed (in kg) by species and fleet segment (trawling, purse seine, and polyvalent). The polyvalent gear includes fish caught by longlines, gillnets, and/or traps, making no distinction between these gears.

Three transects were established along the colonies of both Audouin's (AG) and yellow-legged gulls (YLG), from which all pellets were removed prior to each field season, i.e. to guarantee we would be collecting fresh dietary samples from our study species. After that samples were collected each 3-4 days along the previously described transects to ensure consistency in data collection, during April and May and individually stored in plastic bags. A total of 730 pellets were collected during the breeding seasons of 2019 (N_{AG} = 90, N_{YLG} = 100), 2020 (N_{AG} = 70, N_{YLG} = 70), 2021 (N_{AG} = 100, N_{YLG} = 100) and 2022 (N_{AG} = 100, N_{YLG} = 100). Individual pellet samples are produced 6-24h after a meal (Votier, et al. 2001), thus ensuring to be representative of the most recent dietary preferences of the gull populations.

Pellet samples were examined under a stereomicroscope and separated by prey type: fish (further separated into pelagic and demersal species), refuse, Mollusca, Cephalopoda, Brachyura, Insecta, birds, Rattus rattus, eggshells, and vegetable matter were the main prey-groups found in the pellets. The fish prey items were identified to species-level taxonomic discrimination, using vertebrae and otoliths from our own collection and published identification guides (Assis, 2004; Tuset et al., 2008). Cephalopod beaks were identified using beak collections at our research group (ECOTOP). Inorganic material from refuse was represented by a range of items, including plastic, glass, paper, bones, and organs (e.g. gastrointestinal tract remains) from unknown species, and wood pieces. Some of these items were probably ingested accidentally; nevertheless, they provide indication of the foraging areas used by the species, and therefore were not excluded from the dietary analysis.

Audouin's and yellow-legged gulls were captured at their nests with the help of 'walking-traps' and blood-sampled for stable isotope analysis (SIA), in order to investigate interannual variations in their isotopic niches. A total of 340individual gulls were blood-sampled during the breeding seasons of 2019 (N_{AG} = 20, N_{YLG} = 20), 2021 (N_{AG} = 20, N_{YLG} = 20) and 2022 (N_{AG} = 30, N_{YLG} = 30). Blood samples (ca. 1 ml) were collected from the tarsal vein using 1ml syringes and centrifuged at 12000rpm for 5min within 3–5h of collection to separate red blood cells (RBC) from plasma for SIA (in each year). Stable isotope values obtained from plasma represent the dietary composition during the incubation period, i.e. approximately 5–7days prior to sample collection; Hobson et al., 1994; Cherel et al., 2005). Samples were frozen until preparation for SIA. At the laboratory, plasma samples were treated with successive rinses in a 2:1 chloroform/methanol solution to extract external lipids (Ceia et al., 2012). The relative abundance of stable isotopes of carbon and nitrogen were determined by a continuous-flow isotope ratio mass spectrometer using a CF-IRMS (Isoprime, Micromass, UK). Approximately 0.35 mg of each sample was combusted in a tin cup for determination of nitrogen and carbon isotope ratios. Replicate measurements of internal laboratory standards (acetanilide) indicate measurements errors < 0.1& for both carbon and nitrogen.

Additionally, during the breeding period of 2022 we devided the pellets and blood-samples from breeding gulls into two distinct periods according to the empirical experiment developed under action C8, i.e. prior to the food limitation experiment (15-30 April) and during such experiment (1-15 May).

The proportion of landings for each commercial species was obtained by dividing the amount of a given species in relation to the total amount of marine species landed in a given year (2019 – 2022) during April-May of each year. Frequency of occurrence (FO; %) of each prey species or prey-group was computed as, as the percentage of pellets where a prey type occurred in relation to all pellets collected in each campaign (Alonso et al., 2013), for the pellets of each gull species, in each year, and in each period of the food limitation experiment (pre-experiment and experiment phases). Fish species were devided into pelagic and demersal fish using data available on fishbase (http://www.fishbase.org). Correlations between the amount of (1) pelagic and (2) demersal fish landed by fisheries and present in the diet composition of Audouin's and yellow-legged gulls was measured with Spearman-rank correlations.

Stable Isotope Bayesian Ellipses in R, i.e. *SIBER* (Jackson et al. 2011), were used to calculate the isotopic niches of Audouin's and yellow-legged gulls. Bayesian estimation of standard ellipse area (SEA_B), encompassing 40% of all observations within each group, was calculated using Markov-chain Monte Carlo (MCMC) runs with 2 × 10,000 iterations (Jackson et al. 2011). We extracted 95% credible intervals (CI) of SEA_B, and based on this Bayesian approach we calculated the probability of group 1 (e.g. Audouin's gulls in 2019) SEA being smaller than that of group 2 (e.g. Audouin's gulls in 2021), using the *rjags* R package (Plummer et al. 2019). Standard ellipse areas corrected for small sample size (SEA_C) were computed for visualisation purposes. Bayesian estimates of overlap between standard ellipse areas of diferente groups were scaled to include 95% of data distribution, and calculated for each posterior draw (and averaged over the 1000 draws) using the 'bayesian-overlap' function within *SIBER* R package (Jackson et al. 2011). We extracted 95% CI and calculated the proportion of overlap between the two ellipses, drawn as the proportion of the non-overlapping areas (i.e. $prop_{overlap} = area_{overlap}/(area\ ellipse_2 + area\ ellipse_1 - area_{overlap})$).

3.2 Results and Discussion

3.2.1 Inter-annual changes in fishery landings

Common octopus *Octopus vulgaris* was the commercial marine species most landed by trawlers (51%), followed by common cuttlefish *Sepia officinais* (12%), thickback sole *Microchirus variegatus* (14%) and Atlantic horse mackerel *Trachurus trachurus* (8%) (Fig. 12). There were slight inter-annual variations on the proportion of these main landed prey, with the most noticeable effect being the comparably low overall prey quantity and diversity landed in 2020, likely related with the Covid-19 pandemic period and decrease in fisheries activity during that year (Fig. 12). This fishing method had a noticeably higher diversity on the species caught/ landed when compared to purse-seiners or polyvalent fisheries (Figs. 13 and 14). Purse-seiners mostly targeted chub mackerel *Scomber japonicus* (69%) in their fishery operations over the years, with comparably smaller amounts of European pilchard *Sardina pilchardus* (15%), Atlantic horse mackerel Trachurus trachurus (8%) and blue jack makerel *Trachurus picturatus* (4%) (Fig. 13). Again, a marked decrease in the amount of fish landed in 2020 was evident for this fishing method. Common octopus *Octopus vulgaris* (48%) and chub mackerel *Scomber japonicus* (42%) were the prey dominating the commercial prey landed by polyvalent fisheries (Fig. 14).

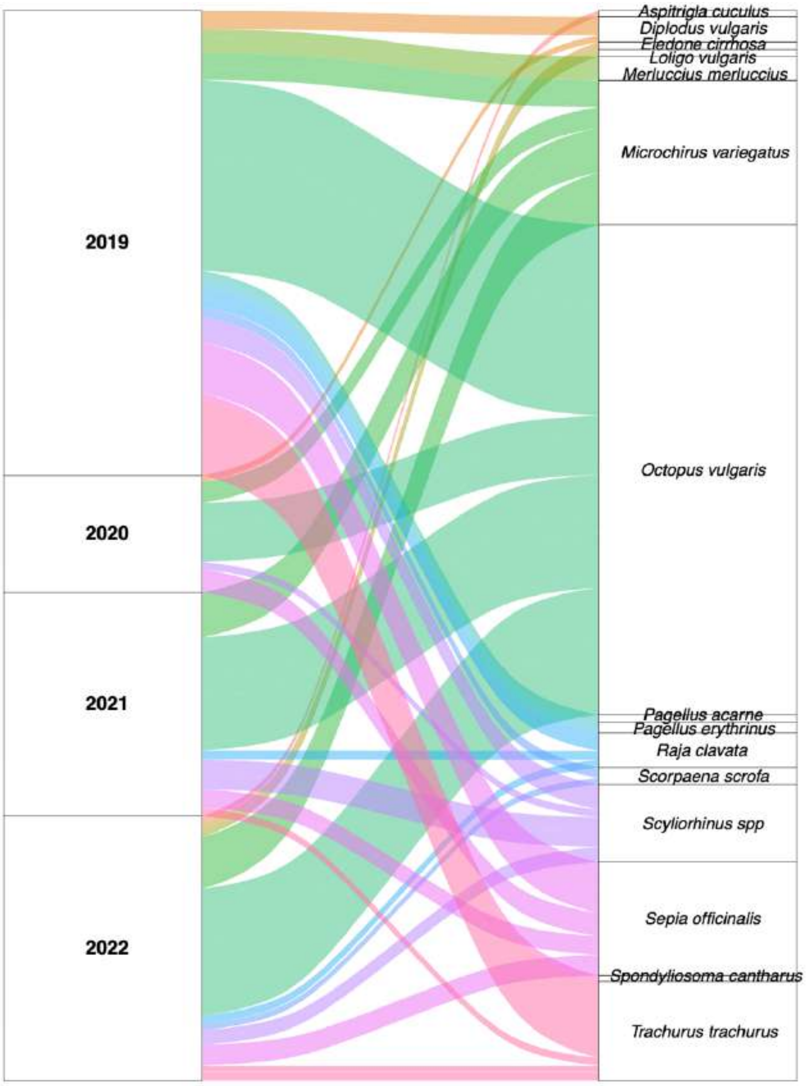

Figure 12 | Alluvial plots on the percentage of different commercial species landed by trawlers at the ports of Quarteira, Olhão and Fuseta (Algarve) during April-May 2019 – 2022. Only species representing a landing proportion > 10% (~370kg) are represented.

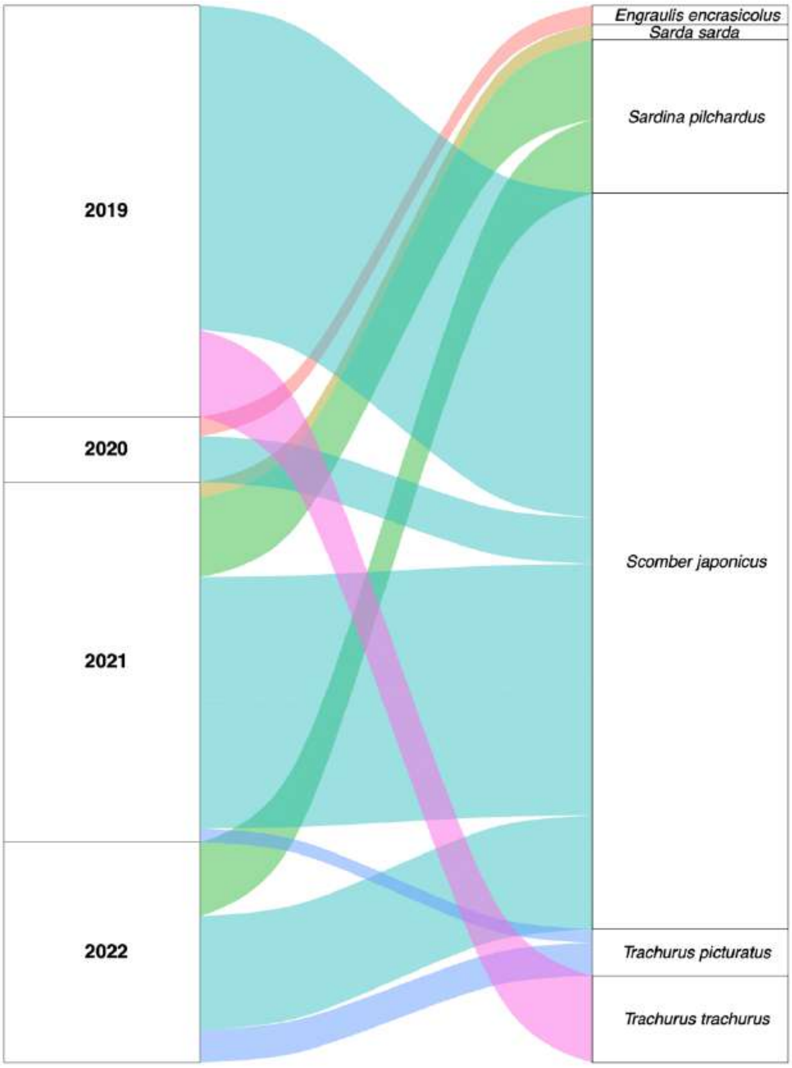

Figure 13 | Alluvial plots on the percentage of different commercial species landed by purse-seiners at the ports of Quarteira, Olhão and Fuseta (Algarve) during April-May 2019 – 2022. Only species representing a landing proportion > 10% (~23 000kg) are represented.

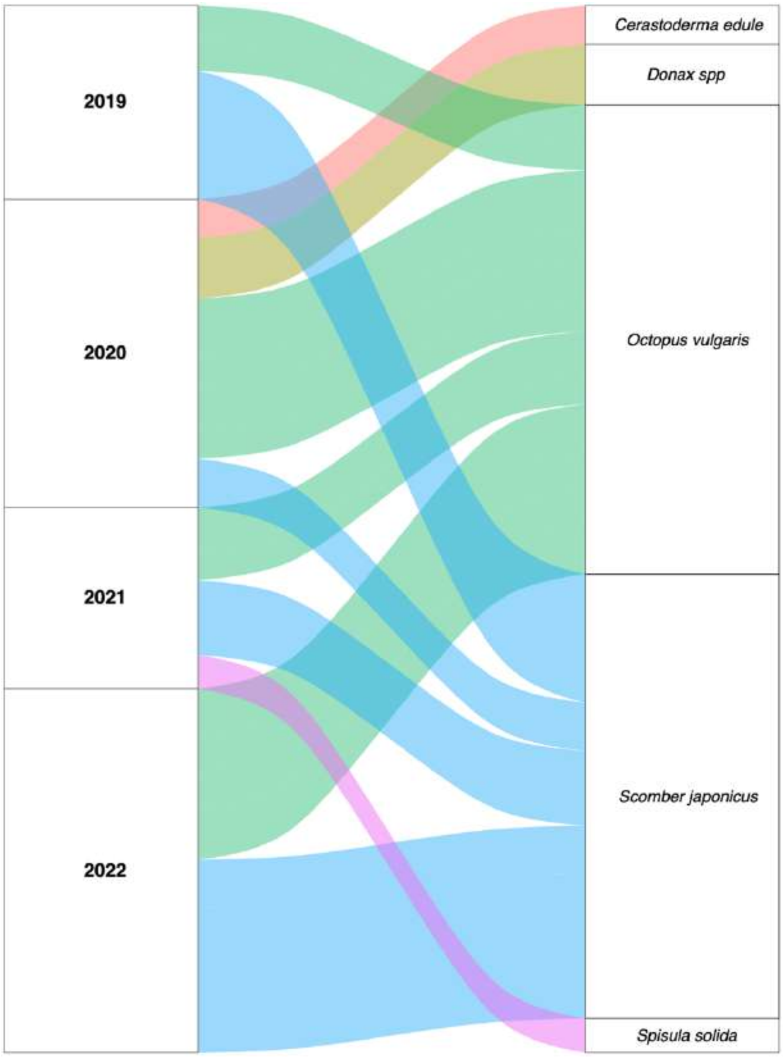

Figure 14 | Alluvial plots on the percentage of different commercial species landed by polivalent vessels at the ports of Quarteira, Olhão and Fuseta (Algarve) during April-May 2019 – 2022. Only species representing a landing proportion > 10% (~23 000kg) are represented.

3.2.2 Inter-annual shifts in gulls' diet

During the four study years, Audouin's gulls based their diet on pelagic fish species (41%), namely garfish/ Atlantic saury *Belone belone*/ Scomberesox saurus (29%) and European pilchard *Sardina pilchardus* (7%) (Fig. 15). They also based their diet on demersal fish (14%), from which seabreams *Diplodus* sp. was the most consumed species (8%). Yellow-legged gulls based their diet on pelagic (20%) and demersal (18%) fish and refuse (22%), with comparably lower prevalence of insects (8%) or Henslow's swimming crab *Polybius henslowii* (7%). By prey species, yellow-legged gulls based their diet on the pelagic species, European pilchard (8%), makerel *Trachurus* sp. (8%) and blue whiting *Micromesistius poutassou* (8%) and the demersal species, seabream (16%) (Fig. 9.4). Interestingly, during 2020 there was a reduction on the amount of refuse and demersal fish, while still relying on similar amounts of pelagic fish and comparably higher quantity of Henslow's swimming crab *Polybius henslowii* (Fig. 15). Despite variations in the percentage of prey species consumed, there was a comparably higher species diversity in the diet of yellow-legged gulls over the years (Fig. 15).

Along the four study years, higher amounts of landed pelagic and demersal fish correlated with higher frequency of occurrence of these groups in the diet of both yellow-legged gulls (pelagics: rs = 0.83, P = 0.01 and demersals: rs = 0.74, P = 0.03) and Audouin's gulls (pelagics: rs = 0.92, P < 0.001 and demersals: rs = 0.82, P = 0.01).

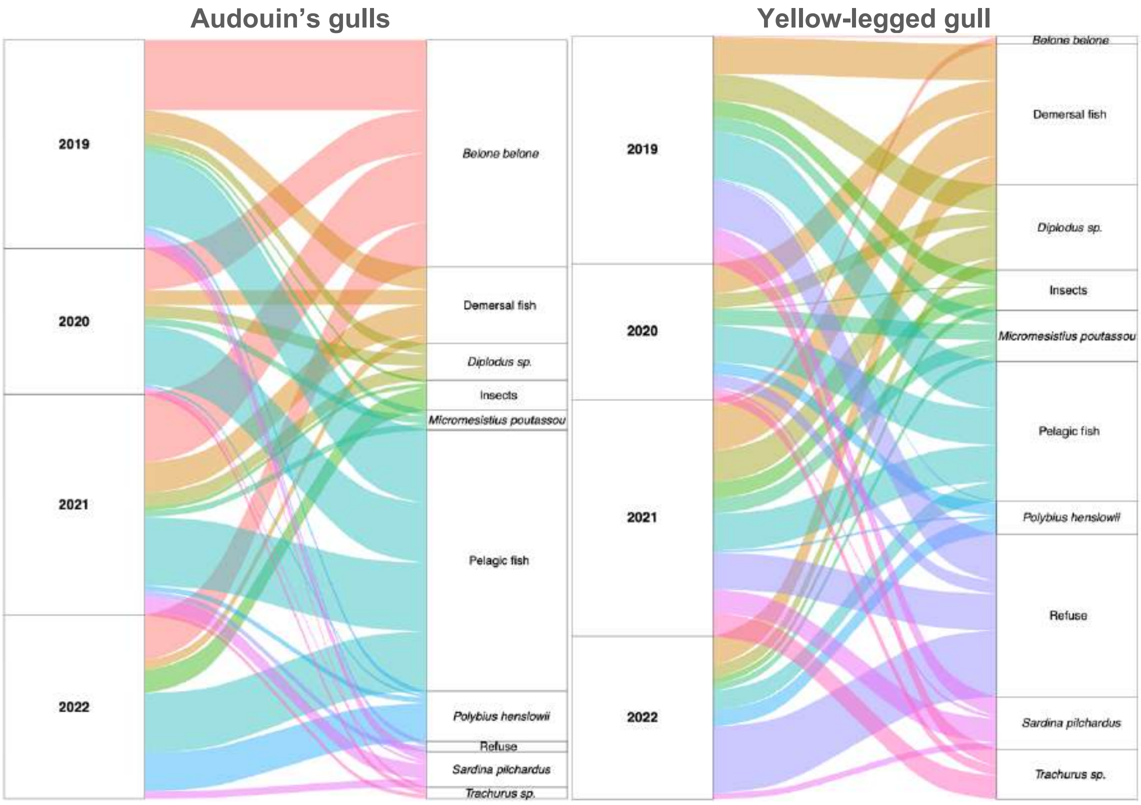

Figure 15 | Alluvial plots on the frequency of occurence (F.O.) of prey in the diet of (left) Audouin and (right) Yellow-legged gulls from Deserta Island (Algarve) during the the breeding periods (April-May) of 2019 – 2022. Only prey with F.O > 10% are represented. **Belone belone*/ *Somberesox saurus,* given the similitude in the aspect/ features of vertebraes of the two pelagic species it was impossible to distinguish between the two.

9.2.3 Inter-annual variation in isotopic niches of breeding gulls

Isotopic niche areas of yellow-legged gulls (YLG) were consistently larger then those of Audouin's gulls (AG) in 2019 (Total Area, TA = 4.5 *vs*. 0.9), 2021 (8.1 *vs*. 1.4) and 2022 (9.2 *vs*. 2.8), respectively for YLG and AG. This is a confirmation of the comparably more generalistic/ opportunistic foraging behaviour of YLG, despite the similitude on the mean isotopic niche occupied by both species, in nitrogen and carbon values. Inter-annual isotopic niche overlaps varied between 8.2% (AG in 2019 vs. AG in 2022) and 91.5 % (YLG in 2021 vs. YLG in 2022) (Fig. 16).

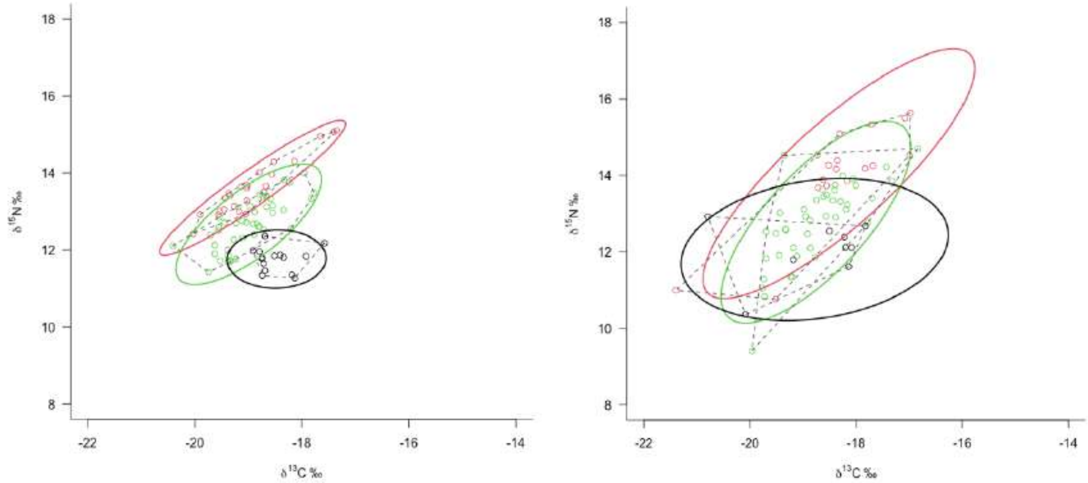

Figure 16 | Isotopic niches (95% siber ellipses) of (left) Audouin's and (right) yellow-legged gulls' plasma, during the incubation periods (April-May) of 2019 (black), 2021 (red) and 2022 (green). The standard ellipse area corrected for small sample sizes (SEA_C) is presented in solid bold lines.

4 | Sources of anthropogenic food available to Yellow-legged gulls

4.1 Breeding seabirds' distribution and habitat use

4.1.1 Methods

Over 3 breeding seasons (2019, 2021 and 2022), we equipped a total of 45 adult Audouin's gulls (*Ichthyaetus audouinii*) and 45 Yellow-legged gulls (*Larus michahellis*) at Deserta Island with Global Positioning System (GPS) loggers (CatLog2; Perthold Engineering, Germany) during incubation (April-May). In April 2022, we also tagged 15 Audouin's gulls and 15 Yellow-legged gulls at Deserta Island with solar powered GPS loggers (OT10-3G and OT15-3G, respectively; Ornitela, Lithuania) that upload information via the Global System for Mobile Communications (GSM). GPS-GSM loggers have the potential to remain active during long periods of time, providing fine-scale geographical information throughout the annual cycle in near real time. Here, we considered: incubation (April-May), chick-rearing (June-August) and post-breeding periods (September-November). Moreover, in 2021 and 2022 we tagged 34 Little terns (*Sternula albifrons*) from two nesting sites at Ria Formosa (17 birds from Fuseta Island and 17 birds from Praia de Faro) with mini-GPS loggers (nanoFixTMGeo & Geo +, PathTrack, UK) during incubation (May). Unfortunately, the COVID-19 lockdown in Portugal coincided with the breeding period of Audouin's and Yellow-legged gulls and Little Terns (May 2020) which impeded deploying and retrieving tracking devices from the study species during that year. To quantify the habitats used by individual seabirds, it was extracted the habitat types in each GPS position from the CORINE Land Cover (CLC) 2018, version 20b2 (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018). To make the distribution maps and the extraction of habitat use classes from CLC to each GPS position we used the '*Extraction*' tools within the software QGIS v. 3.28.2 'Firenze'.

4.1.2 Results and Discussion

4.1.2.1 Audouin's and Yellow-legged gulls

Between 2019 and 2022, we collected geographical information on 28 Audouin's gulls and 33 Yellow-legged gulls during the incubation period at Deserta Island. Analysis of tracking data shows that the overall foraging distributions of Audouin's and Yellow-legged gulls were consistent across the years, but differed between species (Fig. 17). During incubation, Audouin's gulls foraged exclusively at-sea and in deeper and highly productive areas relatively farther from the colony (reaching up to 100 km), especially towards east at the Gulf of Cádiz (Fig. 17). When looking for the information downloaded from the GPS-GSM loggers, it was also verified that Audouin's gulls exhibit the same movement patterns during the chick-rearing with the majority of individual gulls staying close to the colony to regularly feed their offspring (Fig. 18). Nevertheless, some Audouin's gulls exhibited longer foraging trips during the incubation and chick-rearing periods, flying farther from the breeding colony towards the north of Morocco and the Mediterranean sea (Fig. 18). Such long excursions during the breeding period are likely due to the egg predation by Yellow-legged gulls and consequently led to clutch loss. During the post-breeding, Audouin's gulls migrate to their wintering grounds along the west African coast, mainly flying through Morocco, Mauritania and Senegal. In contrast to Audouin's gulls, during incubation Yellow-legged gulls foraged both in marine (i.e. open sea) and terrestrial habitats (Fig. 17).

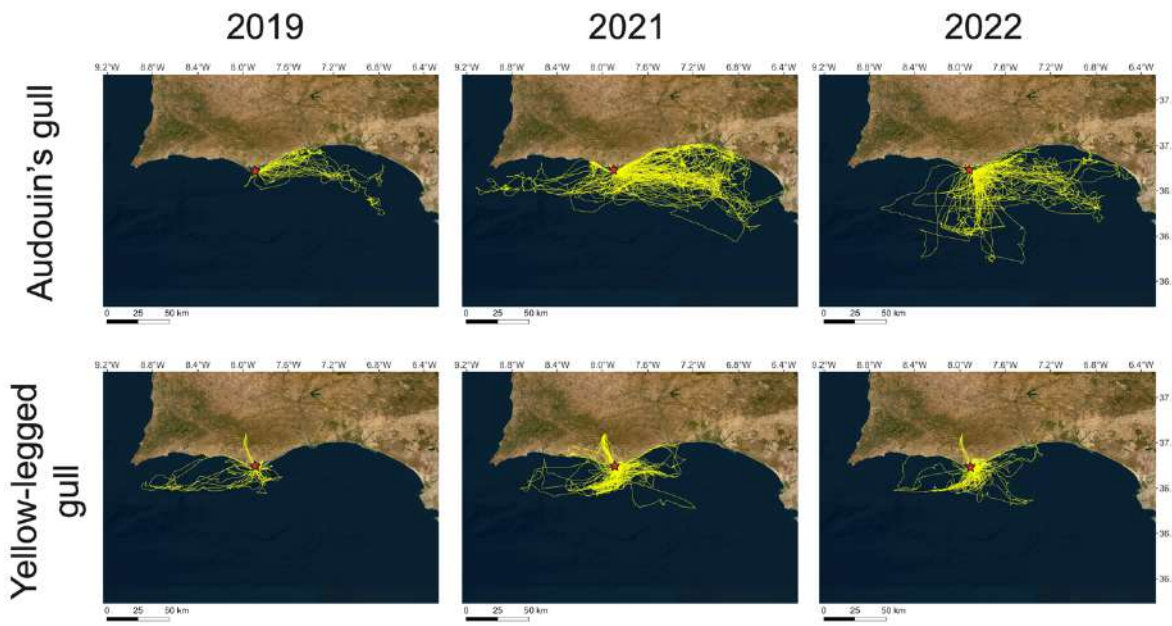

Figure 17 | Foraging distribution of Yellow-legged (*Larus michahellis*) and Audouin (*Ichthyaetus audouinii*) gulls from Deserta Island (red star) between 2019-2022, during incubation (April-May).

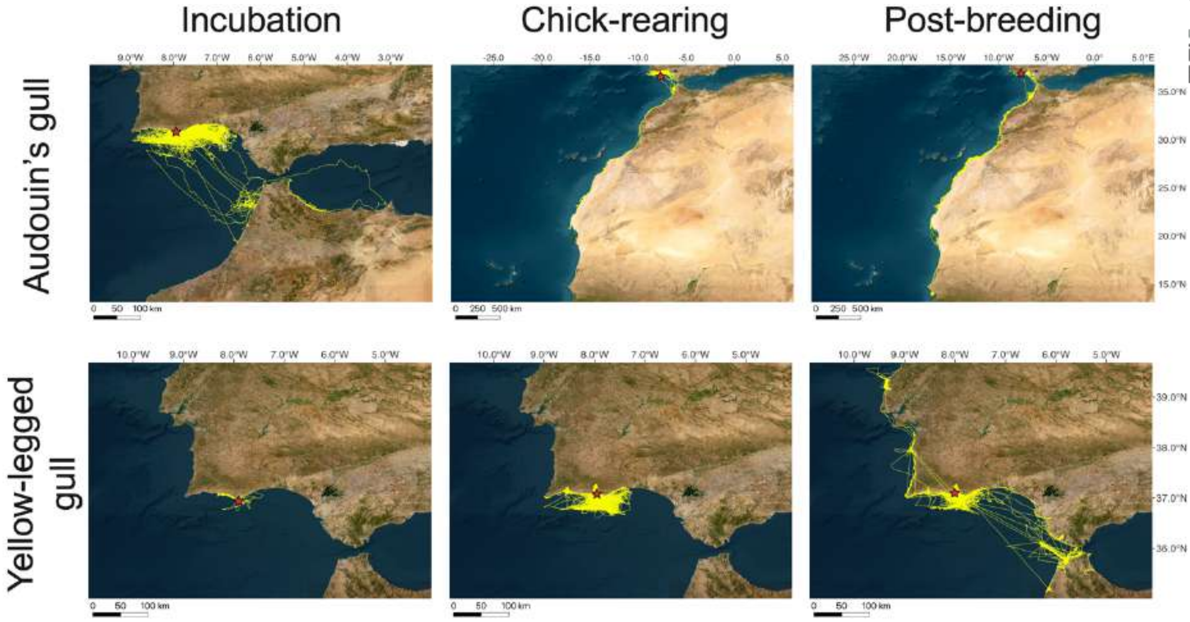

Figure 18 | Foraging distribution of Yellow-legged (*Larus michahellis*) and Audouin (*Ichthyaetus audouinii*) gulls from Deserta Island (red star) during incubation (April-May), chick-rearing (June-August) and post-breeding (September-November) in 2022.

Besides the breeding colony and nearby beaches where they usually rest, in terrestrial environments Yellow-legged gulls frequently use habitats associated with anthropogenic activities, namely urban areas, refuse dumps and fishing harbours (Fig. 19). Across years, individual Yellow-legged gulls were more consistent in their habitat use during incubation (Fig. 19), when compared to the chick-rearing and especially compared to the post-breeding period (Fig. 20). During the post-breeding Yellow-legged gulls start to disperse across the west coast of Central Portugal and North Africa (Fig. 19), making more at-sea excursions and using a variety of terrestrial habitats (Fig. 20).

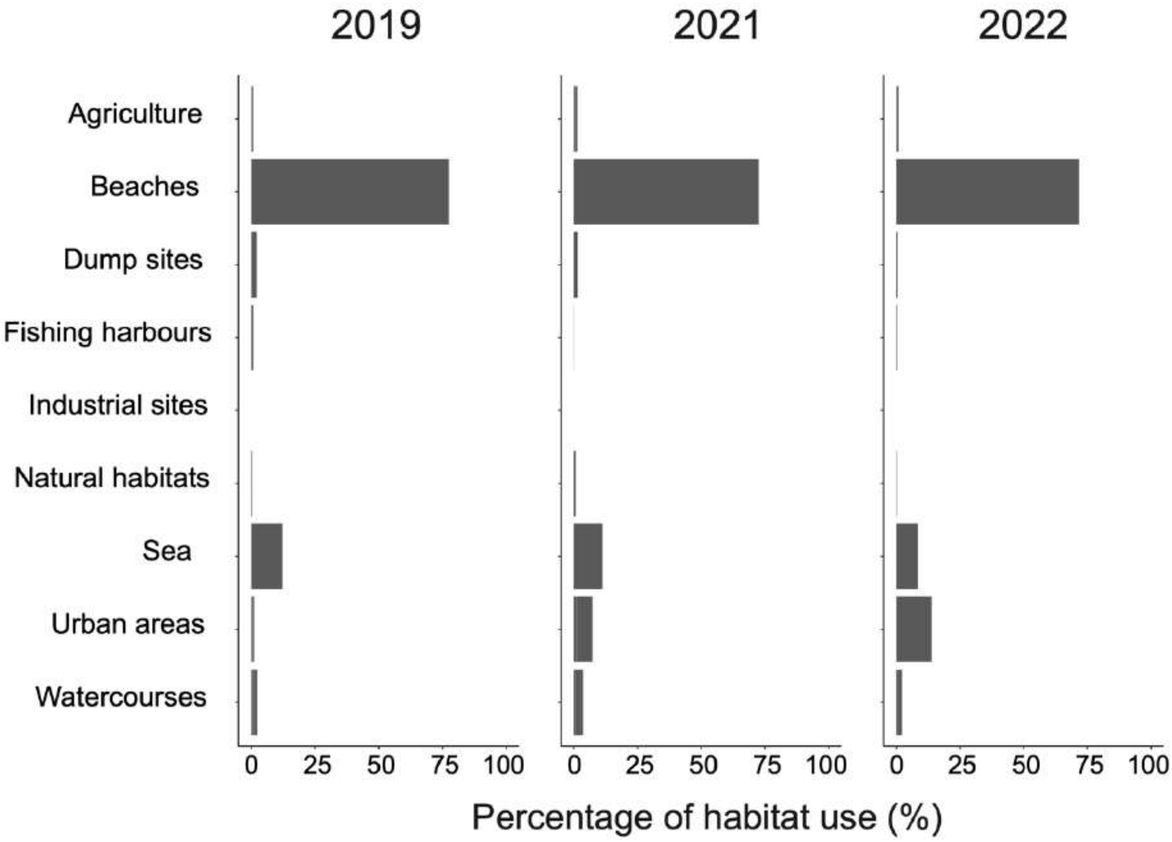

Figure 19 | Habitat use of Yellow-legged gulls (*Larus michahellis*) between 2019-2022, during incubation (April-May).

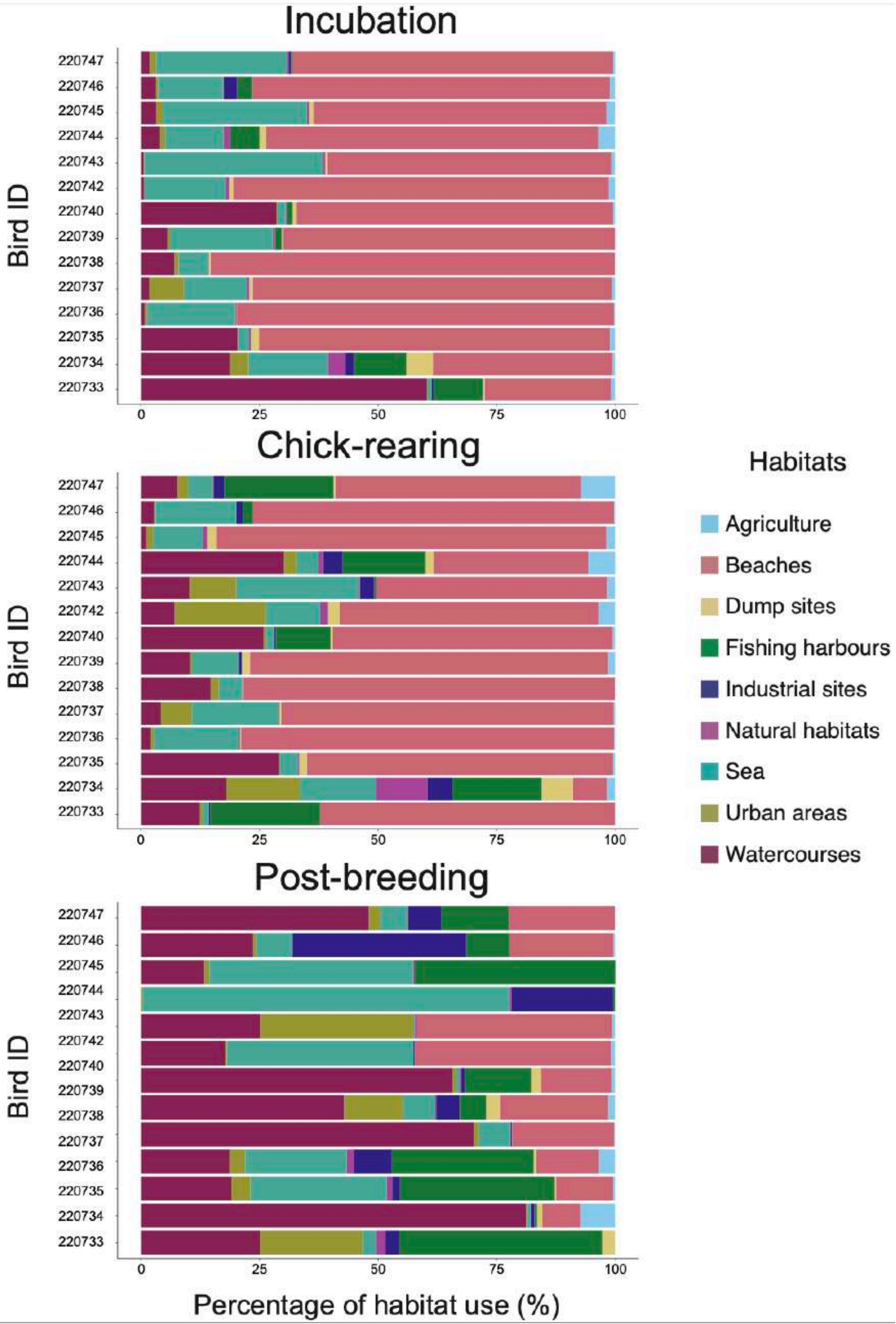

Figure 20 | Habitat use of individual Yellow-legged gulls (*Larus michahellis*) during incubation (April-May), chick-rearing (June-August) and post-breeding (September-November) in 2022.

4.1.2.2 Little terns

Between 2021 and 2022, we collected tracking data from 12 Little terns during the incubation period at Praia de Faro (n=5) and Fuseta Island (n=7). Tracking of Little Terns suggests that many foraging trips to the lagoon system, intertidal flat and nearby salinas are important for incubating Little Terns, mainly for feeding or resting (Fig. 21). However, the use of these habitats varied between years and colonies (Fig. 22). Tracking of Little Terns also shows that this species can make sporadic foraging trips to the ocean, possibly to target marine prey species, which are of higher energetic value than the estuarine lagoon fish species.

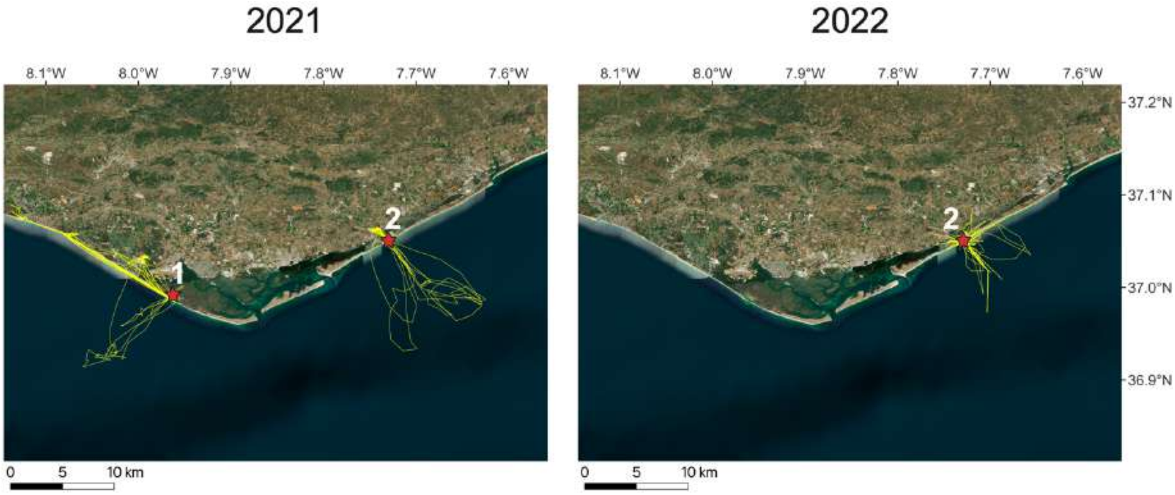

Figure 21 | Foraging distribution of Little terns (*Sternula albifrons*) from (a) Praia de Faro and (b) Fuseta Island (red stars) between 2021-2022, during incubation.

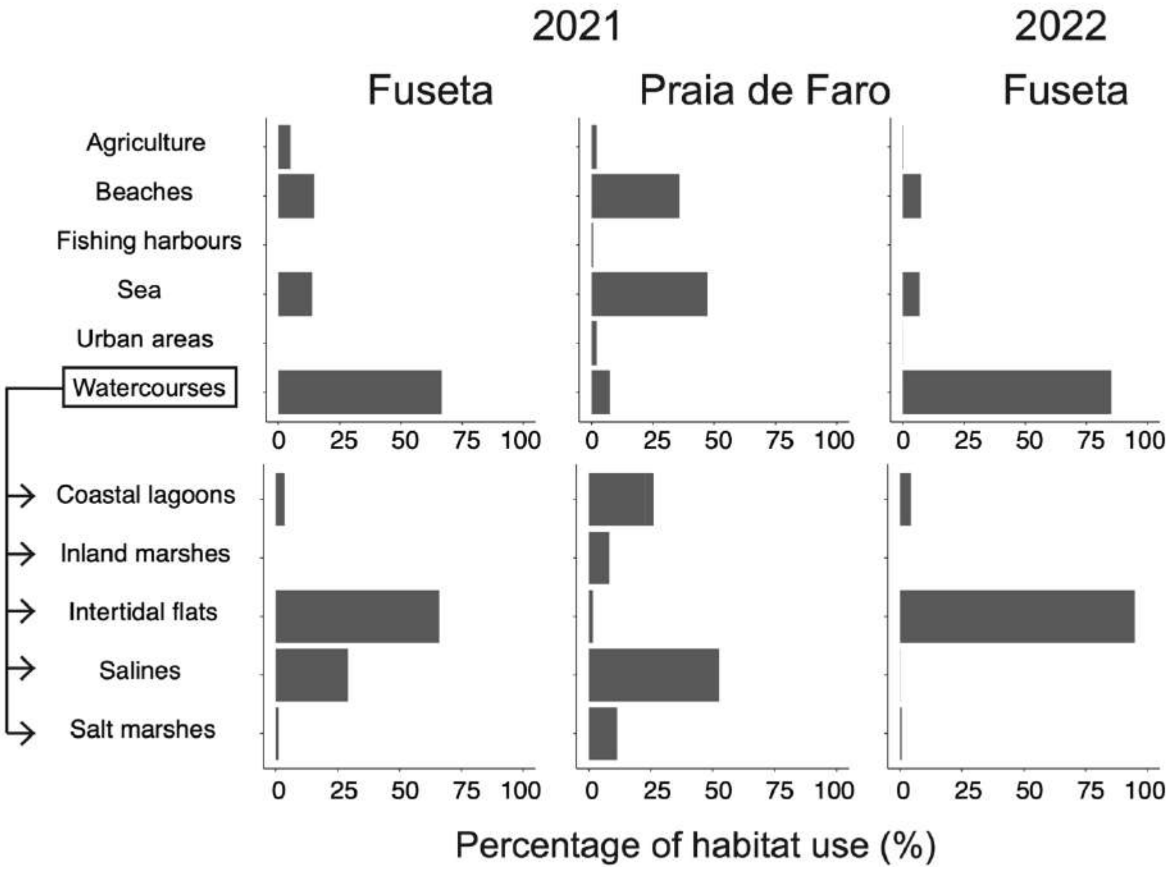

Figure 22 | Habitat use of Little terns (*Sternula albifrons*) from (a) Praia de Faro and (b) Fuseta Island (red stars) between 2021-2022, during incubation.

4.2 Monitoring gulls at fishing harbours and in the landfill

4.2.1 Methods

Monitoring gulls at fishing harbours and in the landfill

To identify sources of anthropogenic food for the population of Yellow-legged gulls breeding at Barreta Island, monthly gull counts were carried out in Olhao and Culatra fishing harbour, as well as in the Sotavento landfill (Fig. 23).
Bird counts at fishing harbours followed a transect covering the entire area, with a minimum of 3 counts per monitoring day, with an interval of 1 hour between counts. All gull species were counted and their behaviour recorded. The counts were performed twice a month from January 2020 to April 2022, except in May and June when the counts were made twice a week, with one of the counts on a weekday and the other on the weekend. To cover the entire time of bird activity, counts were made at different times of the day.
At the Sotavento landfill, counts were made at vantage points, done every hour throughout the day with a minimum of 8 counts per day. The counts were performed twice a month from June 2020 to April 2022, except in May and June when the counts were made twice a week, with one count on a weekday and the other on the weekend.
During monitoring, gull species were identified, counted, and the age and behaviour recorded (feeding, landed, in flight). It was also registered the time of the observation and the start and end time of the transect. Spatial position of birds was also recorded in 25*25 m grids of the Sotavento landfill and Olhao and Culatra fishing harbours.
Paired *t* tests were used to evaluate differences in the mean abundances of gulls on fishing harbours and the landfill during weekdays and weekends. It was assumed significant differences at values of $p < 0.05$.

Figure 23 | Location of the study sites used during gull countings in fishing harbours and the landfill.

Monitoring ringed Yellow-legged gulls

During the breeding seasons of Yellow-legged gulls in 2020 and 2021, ringing campaigns, to mark chicks with colour rings, were performed in the colonies of Barreta/Deserta and Culatra island. The histories of marked gulls observed and reported during the period from July 2020 to April 2022 were used to access the distribution and identify feeding sites.

4.2.2 Results and Discussion

Monitoring gulls at fishing harbours and in the landfill

Fishing harbours

Between January 2020 and April 2022, a total of 195 counts were made in the Olhão fishing harbour and 196 in the Culatra fishing harbour. In total nine species of gulls and four species of terns were observed (Table 14).

Table 14 | Total number of birds observed in 195 counts in Olhão fishing harbour and in 196 counts in Culatra fishing harbour during January 2020 and April 2022.

Species	Olhão	Culatra
Larus argentatus	1	0
Ichthyaetus audouinii	420	120
Larus delawarensis	0	2
Larus fuscus	5938	8547
Larus genei	5	1
Larus michahellis/Larus fuscus	5268	6583

Larus marinus	2	72
Larus melanocephalus	312	36
Larus michahellis	14830	18843
Larus ridibundus	555	29
Larus sp.	2594	2201
Sterna hirundo	0	2
Sterna sp.	0	2
Sternula albifrons	85	82
Thalasseus sandvicensis	14	22
Hydroprogne caspia	3	0

The two main species attending the fishing harbours were the Yellow-legged gull and the Lesser black-backed gull. Although both species are present throughout the year, the number of Lesser black-backed gulls decreases sharply between April and August (Fig. 24), at the time of the breeding season. For the Yellow-legged gull, a resident species, the number of gulls is more or less constant throughout the year, with a slight increase in August and September (Fig. 24), probably related to the income of juveniles that abandoned the colony. For Audouin's gull, the presence in fishing harbours was low, with the peak of abundance registered in June (Fig. 24), however, this species has never been recorded feeding on waste or discards, only flying or roosting with other gulls. Little terns were also registered in low abundance but occasionally seen fishing in the waters of the fishing harbours (Fig. 24).

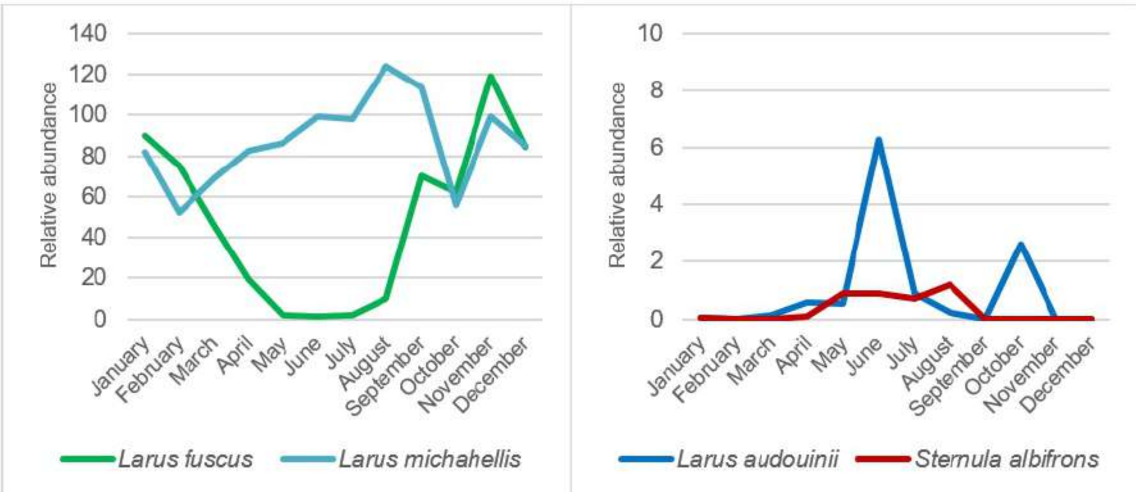

Figure 24 | Relative abundance (number of birds per count) of Lesser black-backed gull (Larus fuscus), Yellow-legged gull (*Larus michahellis*), Audouin's gull (*Larus audouinii*), and Little tern (*Sternula albifrons*).

At Olhão fishing harbour the number of large gulls (here considered the Yellow-legged gull and the Lesser black-backed gull) varied monthly between a minimum of 49 and a max of 582 gulls per count, with the highest values between August and February (Fig. 25), probably reflecting the income of Lesser-black-backed gulls wintering in the region. The mean number of gulls attending was significantly higher (t_{23} = 3.56, p = 0.002) during the weekdays than on the weekends ($m_{weekday}$ = 218.9; $m_{weekend}$ = 137.6), probably related to the fishing activity, which is lower during weekends.

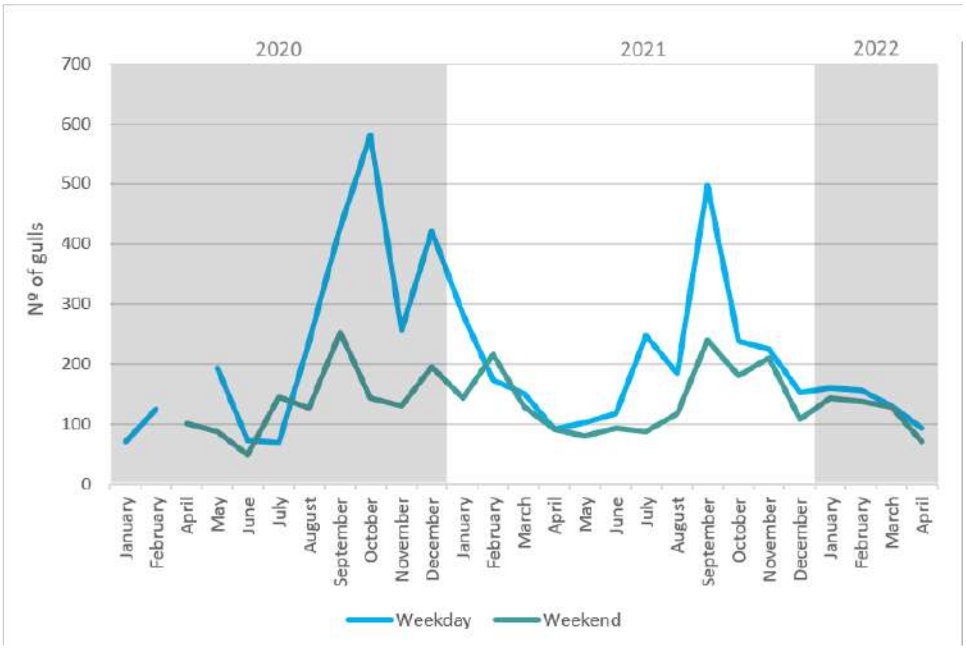

Figure 25 | Mean number of gulls (Yellow-legged gull and Lesser black-backed gull) observed in Olhão fishing harbour during monthly counts during weekdays and weekends from January 2020 to April 2022.

Regarding only Yellow-legged gulls the mean number per count varied between 24 and 220, with peaks between August and December of 2020 (Fig. 26). The mean number of yellow-legged gulls attending the Olhão fishing harbour was also significantly higher (t_{23} = 3.14, p = 0.004) during the weekdays than in the weekends ($m_{weekday}$ = 98.0; $m_{weekend}$ = 65.2).

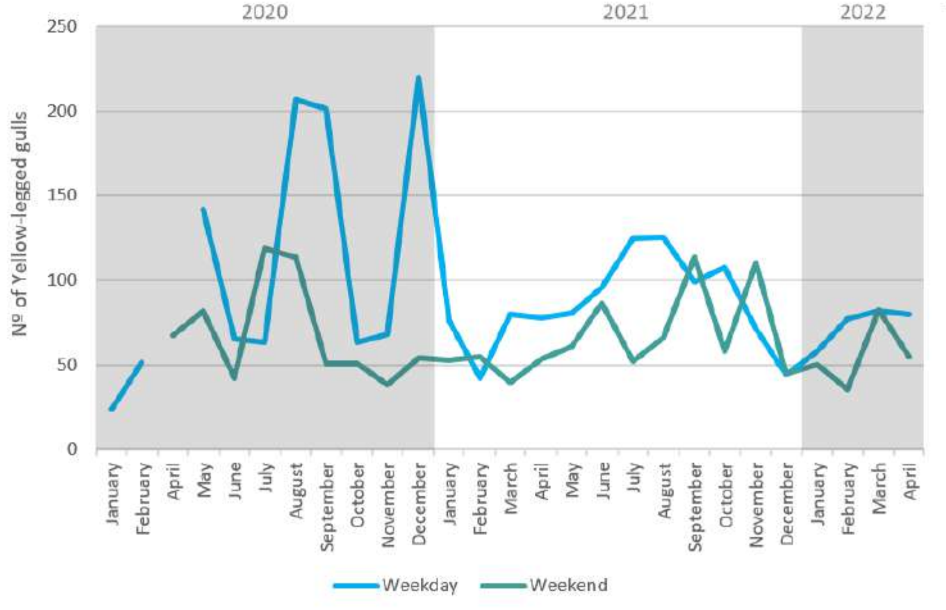

Figura 26 | Mean number of Yellow-legged gulls observed in Olhão fishing harbour during monthly counts during weekdays and weekends from January 2020 to April 2022.

At Culatra fishing harbour the number of large gulls varied monthly between a minimum of 40 and a max of 430 gulls per count, with the highest values between November and February (Fig.27). The mean number of gulls was not significantly different (t_{23} = 0.39, p = 0.699) between weekdays and weekends ($m_{weekday}$ = 210.7; $m_{weekend}$ = 202.3).

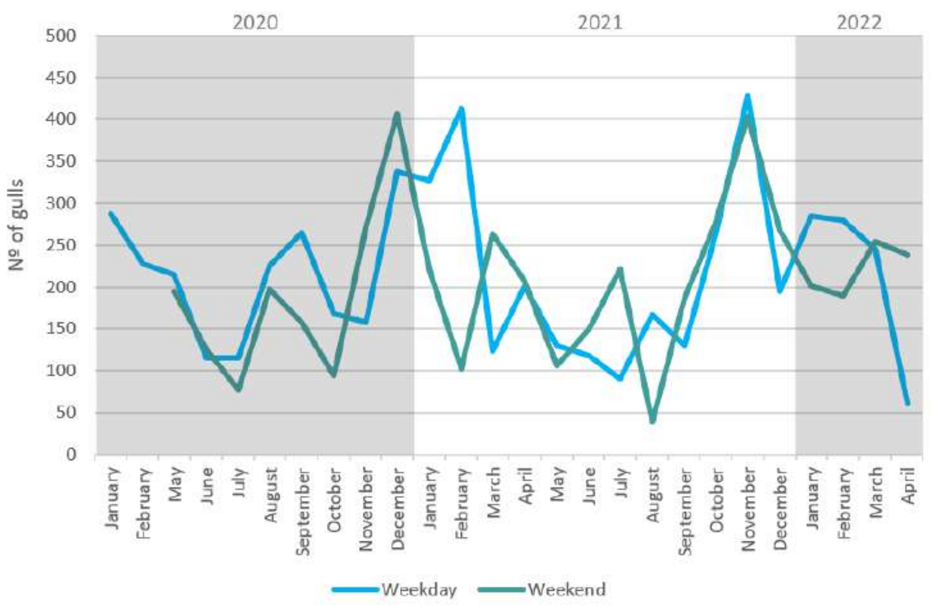

Figura 27 | Mean number of gulls (Yellow-legged gull and Lesser black-backed gull) observed in Culatra fishing harbour during monthly counts during weekdays and weekends from January 2020 to April 2022.

For Yellow-legged gulls, the mean number per count varied between 24 and 244 (Fig.28). Similarly to the number of large gulls, the mean number of yellow-legged gulls attending the Culatra fishing harbour was not significantly different ($p = 0.180$; $t(23) = 1.38$) between weekdays and weekends ($m_{weekday} = 108.1$; $m_{weekend} = 89.6$).

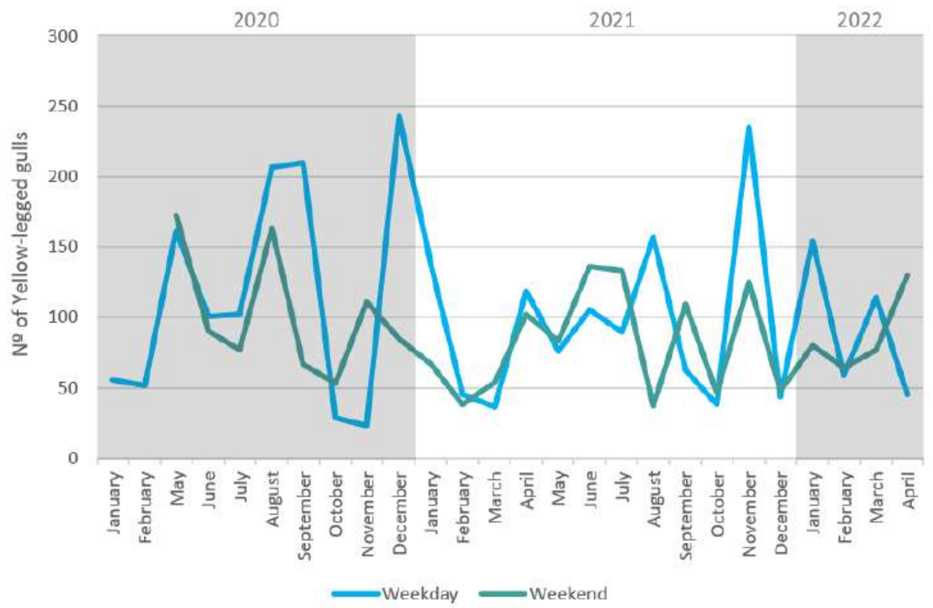

Figura 28 | Mean number of Yellow-legged gulls observed in Culatra fishing harbour during monthly counts during weekdays and weekends from January 2020 to April 2022.

Of all the Yellow-legged gull sightings, only 4% were seen actively feeding in the fishing harbours, although more than 75% were recorded landed, resting, or waiting for an opportunity to feed.
Most of the food availability for gulls in the fishing harbours comes, not from the moment of fish landings, but when fishermen are cleaning the nets and throwing fish scraps on the water or purposely feeding the gulls. Other food sources are related to the presence of fish or other food scattered on the floor, people purposely giving food, and gulls trying to find food in the garbage (Fig. 29).

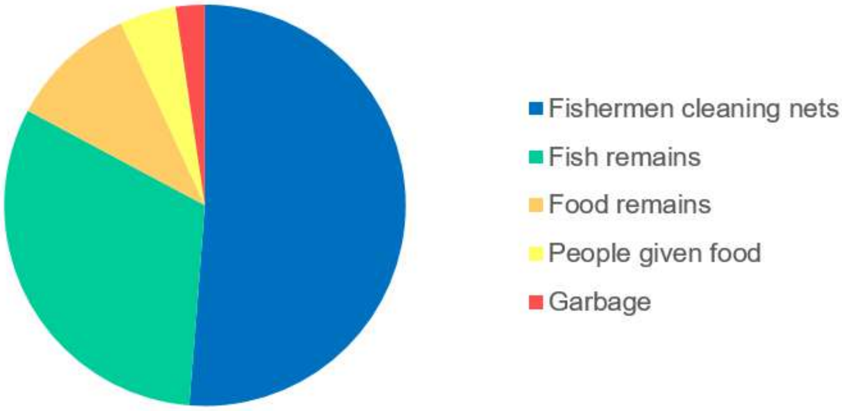

Figura 29 | Available food choices for Yellow-legged gulls in the fishing harbours of Olhão and Culatra.

In Olhao fishing harbour gull feeding places are mainly in areas where the fishing boats are located, and near the fish market (Fig. 30). Given the smaller size of Culatra, gull feeding areas are spread throughout the harbour with main areas located in places where fishermen usually clean nets (Fig.31).

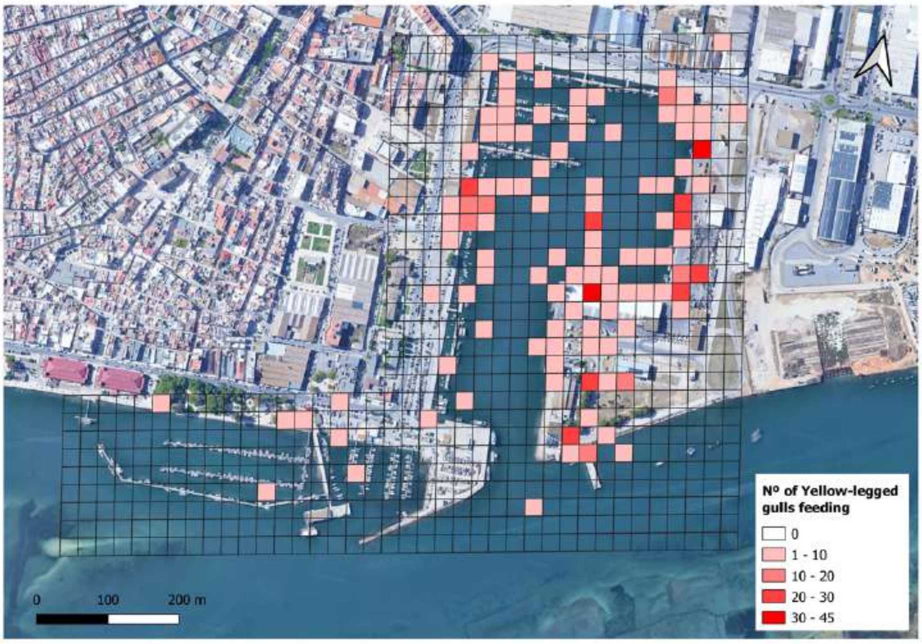

Figure 30 | Feeding areas of gulls in Olhão fishing harbour, recorded in a 25*25 m grid, during monthly counts from January 2020 and April 2022.

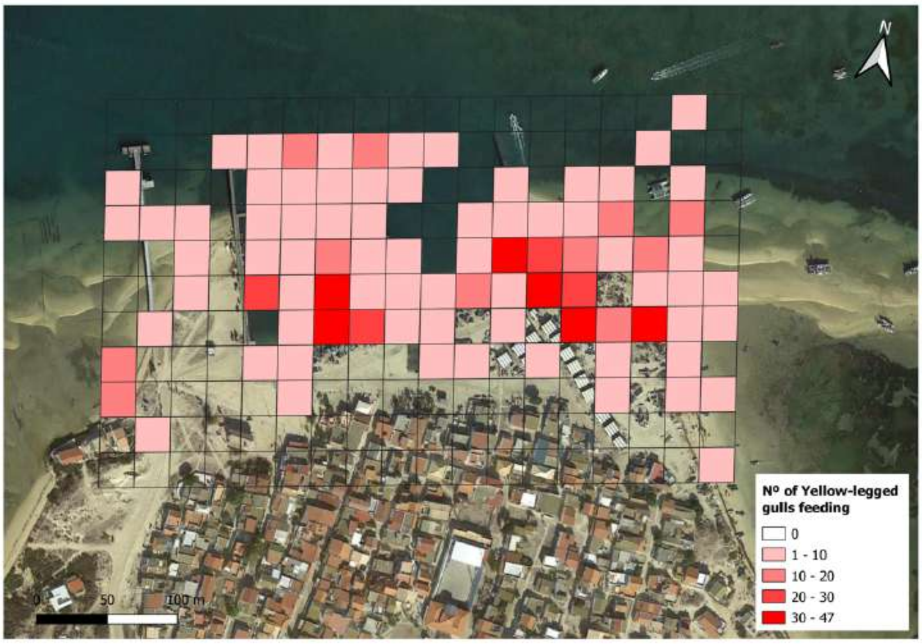

Figure 31 | Feeding areas of gulls in Culatra fishing harbour, recorded in a 25*25 m grid, during monthly counts from January 2020 and April 2022.

Monitoring gulls at the landfill

Between June 2020 and April 2022, a total of 408 counts were made in the Sotavento landfill, in a total of 53 days (27 days on weekdays and 26 on weekends). Five species of gulls were registered in the landfill (Table 5), with the most abundant species being the Yellow-legged gull and the Lesser black-backed gull. The Audouin's gull was recorded during May and June with a maximum of 69 individuals attending the landfill. Although they were observed landing close to the operation zone, there were no records of them feeding.

Table 5 | Total number of birds observed in 408 counts in the Sotavento landfill between June 2020 and April 2022.

Species	N
Aegypius monachus	2
Aquila fasciata	1
Ardea cinerea	22
Ciconia ciconia	113520
Corvus corax	4
Gyps fulvus	5
Ichthyaetus audouinii	155
Larus fuscus	9581
Larus michahellis/Larus fuscus	21951
Larus melanocephalus	1
Larus michahellis	16756
Larus ridibundus	3969
Larus sp.	52746
Milvus migrans	44
Milvus milvus	17

Number of large gulls was higher between December and March up to almost 5000 gulls (Fig. 32), with large numbers of Lesser black-backed gulls wintering in the region. The lowest abundance was recorded in August 2021 with no gulls attending the landfill. The mean number of gulls was not significantly different ($p = 0.185$; $t(22) = -1.37$) between weekdays and weekends ($m_{weekday} = 734.9$; $m_{weekday} = 907.7$).
Mean number of Yellow-legged gulls varied from zero in August of 2021 to 707 in March 2022 (Fig. 33) and was not significantly different ($p = 0.575$; $t(18) = 0.570$) between weekdays and weekends ($m_{weekday} = 185.2$; $m_{weekend} = 162.5$).
Overall, the number of immature gulls attending the landfill was higher (Fig. 34) ($m_{adults} = 171.9$; $m_{immatures} = 291.9$), but monthly differences were not significant ($p = 0.336$; $t(21) = -0.984$). On the other hand, during the breeding period (April to June), the number of adult Yellow-legged gulls feeding in the landfill was higher than the number of immatures. Feeding areas include the locations where the garbage is dumped (Fig. 35), with a preferred feeding time during the morning between 7 am to 11 am, when most operations (landing and compacting waste) took place (Silva, 2021).

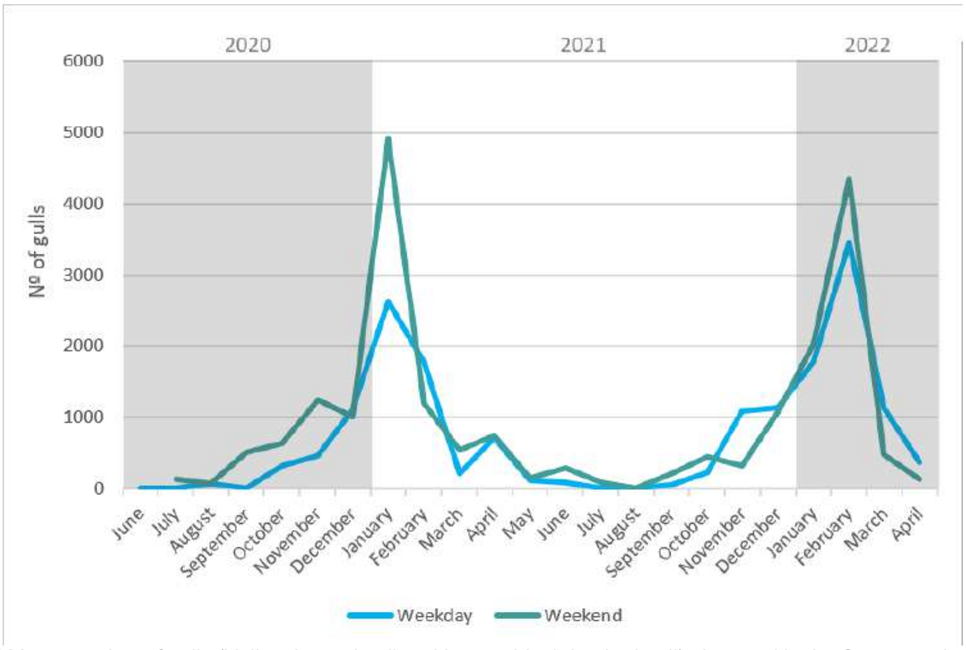

Figura 32 | Mean number of gulls (Yellow-legged gull and Lesser black-backed gull) observed in the Sotavento landfill during monthly counts during weekdays and weekends from June 2020 to April 2022.

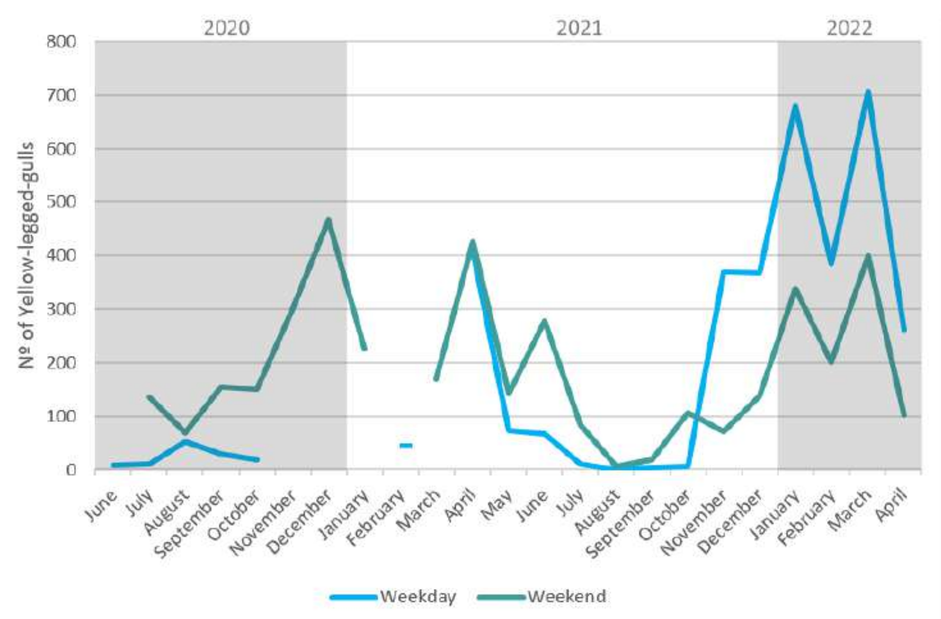

Figura 33 | Mean number of Yellow-legged gulls observed in the Sotavento landfill during monthly counts during weekdays and weekends from June 2020 to April 2022.

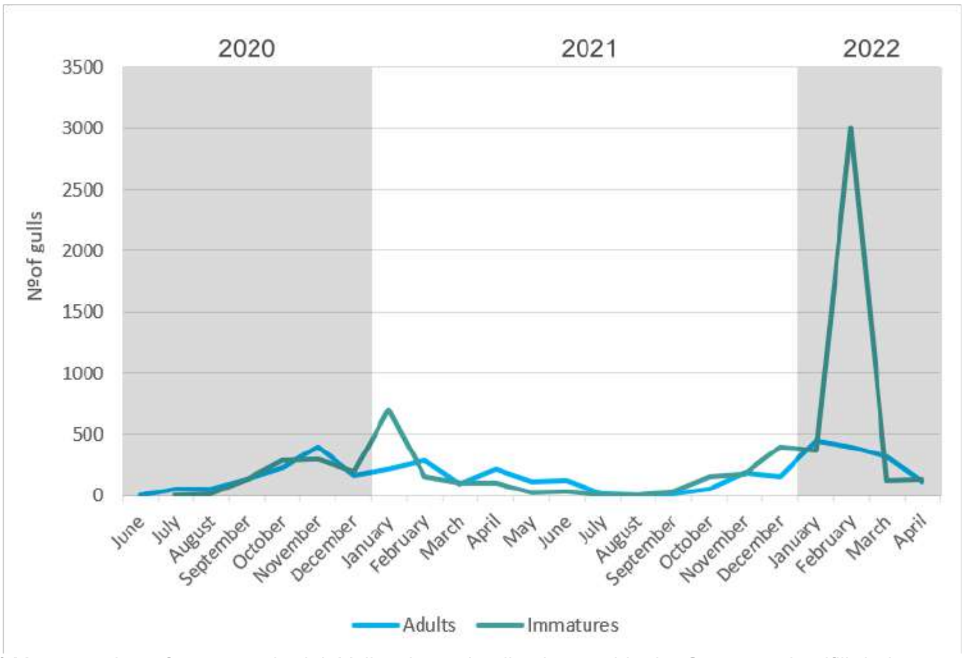

Figure 34 | Mean number of young and adult Yellow-legged gulls observed in the Sotavento landfill during monthly counts during weekdays and weekends from June 2020 to April 2022. Note: it was also registered an increase in the number of gulls in January-February 2021 similar to the one registered in 2022, however during those counts gulls were not distinguished by age.

Figura 35 | Feeding areas of gulls in Sotavento landfill, recorded in a 25*25 m grid, during monthly counts from June 2020 and April 2022.

Monitoring ringed Yellow-legged gulls

During the breeding seasons of 2020 and 2021, a total of 395 Yellow-legged gulls were ringed on Deserta island and 49 on Culatra island. Until April 2022, 553 ringed gull controls were reported, from 227 individuals. Most of the sightings were reported in the south of the Iberian Peninsula, but there were also records on the west coast (Fig. 36). Maximum distances of adults were mainly distributed within a radius of 50 km around the colonies, while immatures were frequently observed at distances greater than 100 km (Canário, 2022).

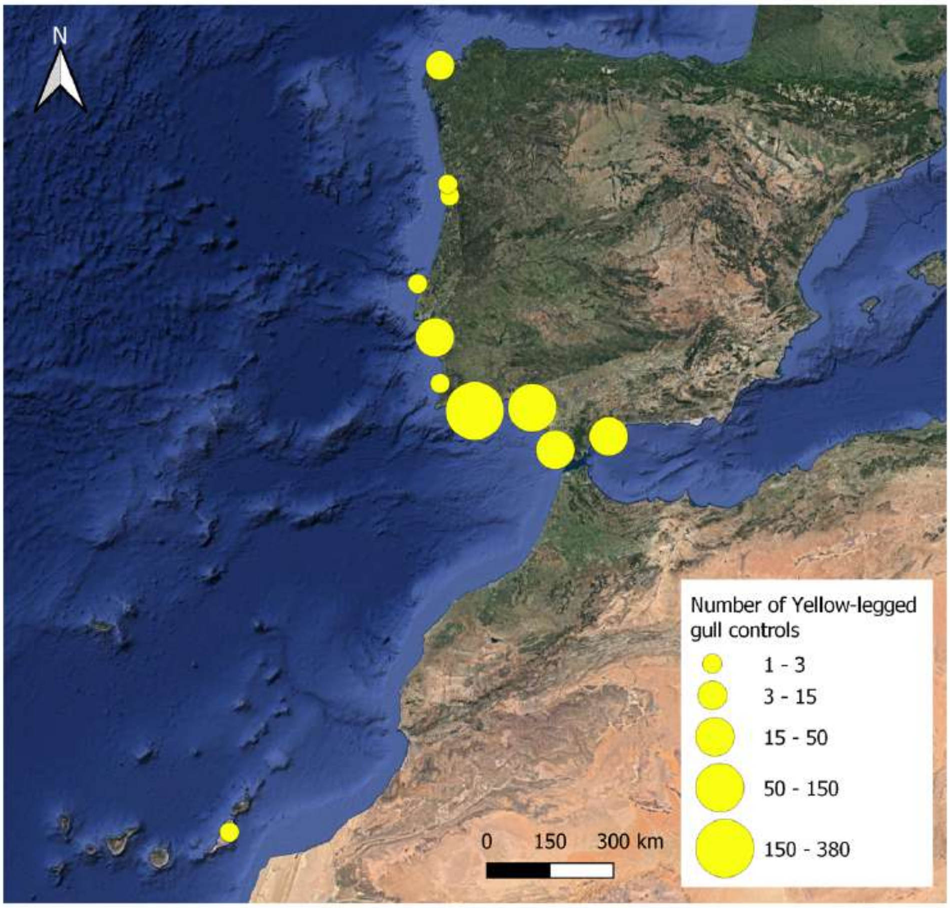

Figure 36 | Locations of the reported controls of Yellow-legged gulls ringed in Deserta and Culatra colony since 2019.

Most of the birds were seen in fishing harbours, followed by salt pans and beaches (Fig. 37). The presence of birds in places with greater availability of anthropogenic food sources (considered here the fishing harbours, landfills, and urban areas), represented a total of 59% of the total controls.

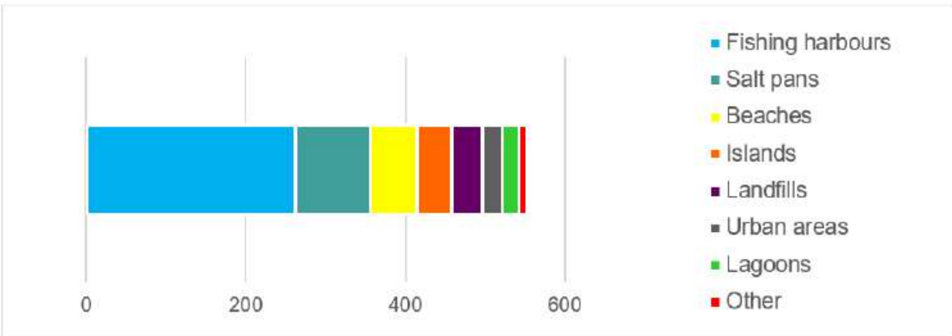

Figure 37 | Habitat use of ringed Yellow-legged gulls between June 2020 and April 2022.

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APPENDIX

Appendix A

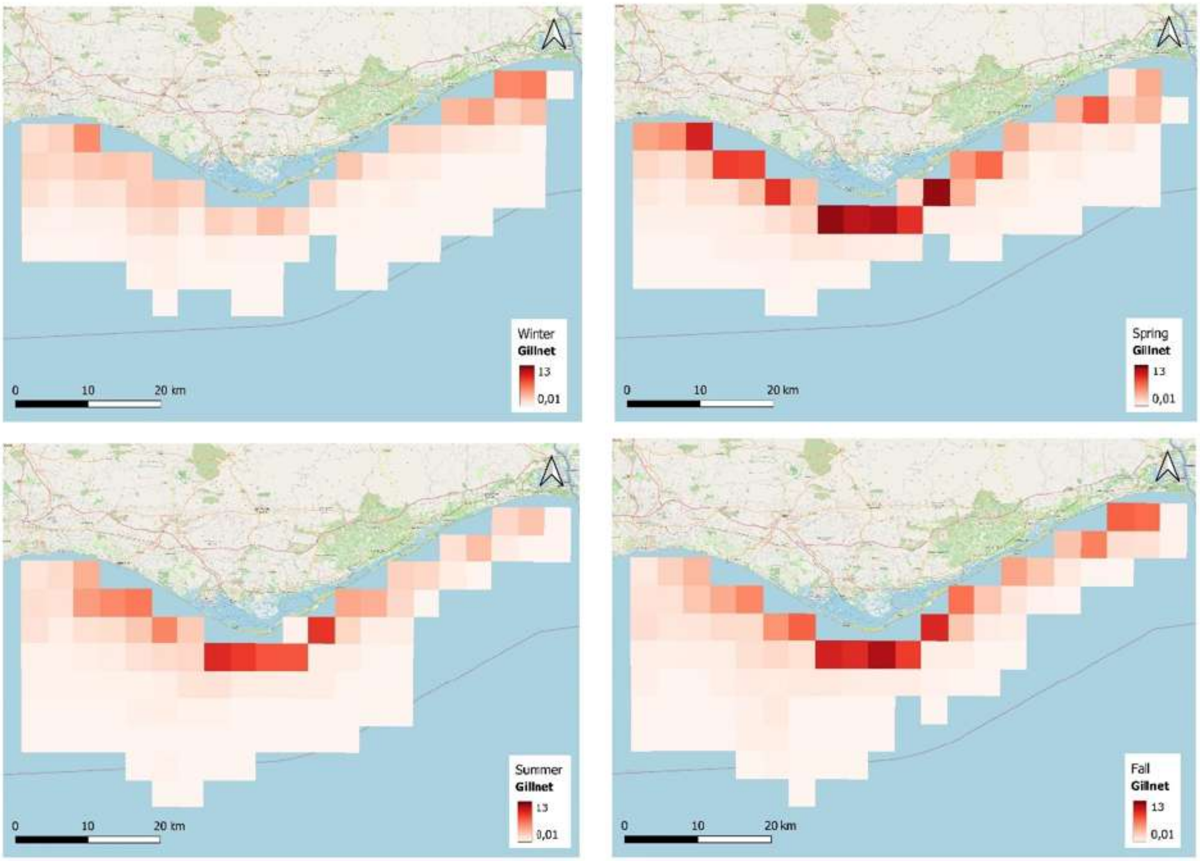

Fig. A.1 – Distribution maps of fishing effort of vessels opperating gillnets during winter (January to March), spring (April to June), summer (July to September), and fall (October to December).

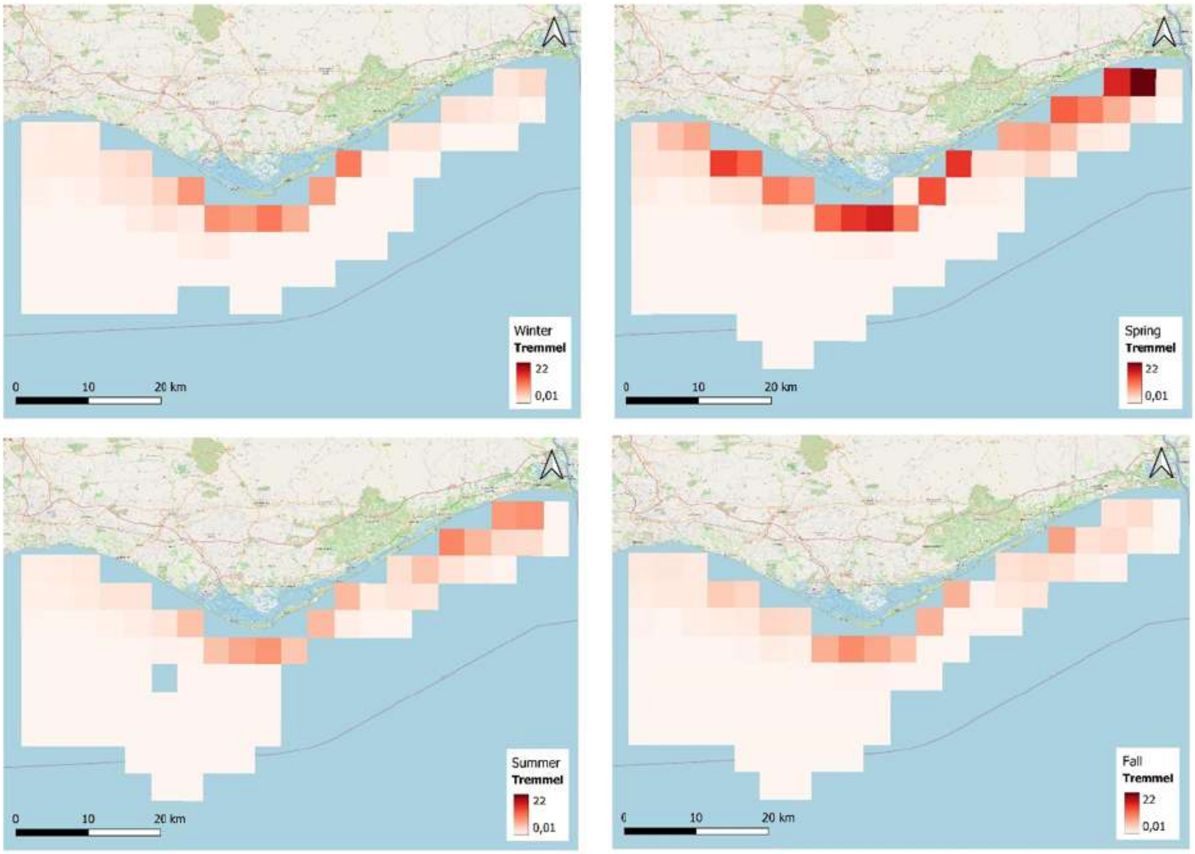

Fig. A.2 – Distribution maps of fishing effort of vessels operating tremmel during winter (January to March), spring (April to June), summer (July to September), and fall (October to December).

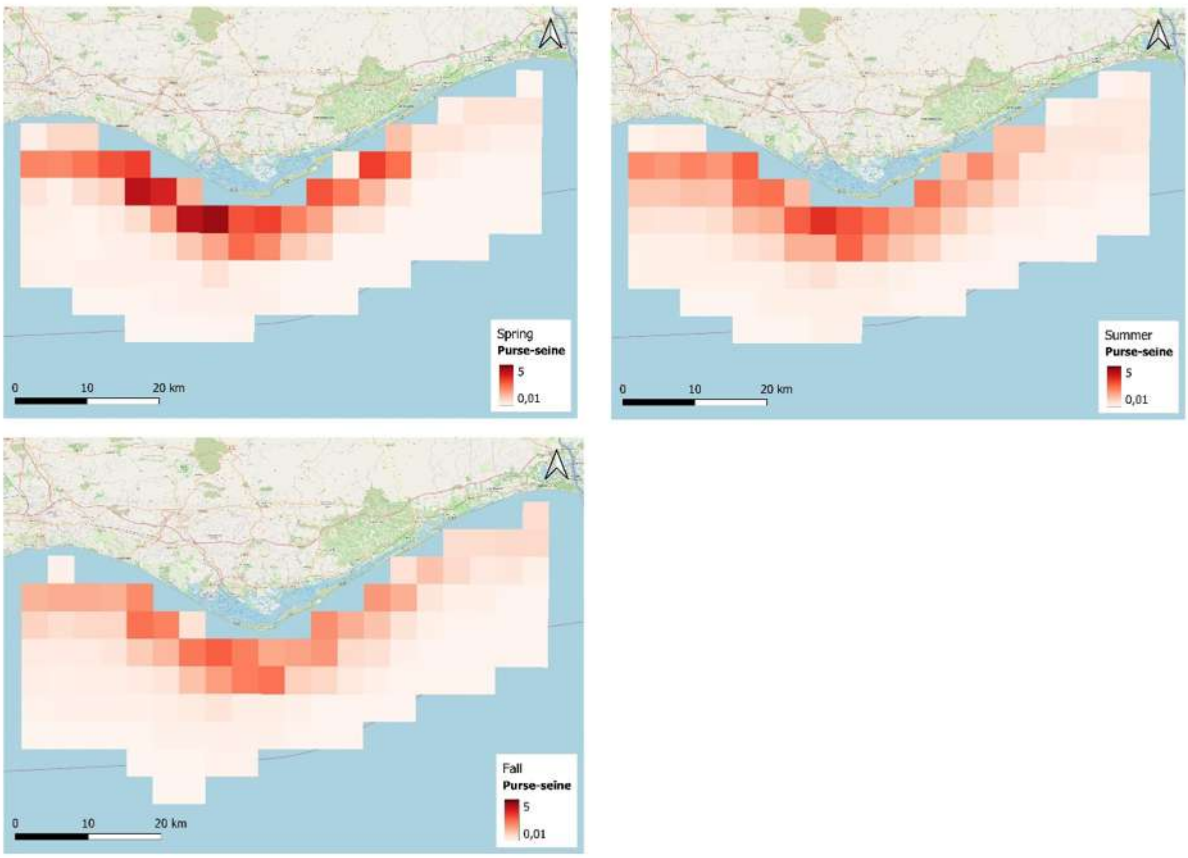

Fig. A.3 – Distribution maps of fishing effort of vessels opperating purse-seines during spring (April to June), summer (July to September), and fall (October to December).