ICES Journal of Marine Science, 2023, **80**, 2405–2413
DOI: 10.1093/icesjms/fsac120
Advance access publication date: 1 July 2022
Original Article

Age-related differences in foraging behaviour at sea and interactions with fishing vessels in an opportunistic urban gull

Míriam Gimeno [1], José Antonio García [1], Isabel Afán [2], Raül Aymí [3], Tomás Montalvo [4], and Joan Navarro [1,*]

[1] Institut de Ciències del Mar (ICM), Passeig Marítim de la Barceloneta, 37-49, 08003 Barcelona, Spain
[2] Estación Biológica de Doñana—CSIC, Avenida Américo Vespucio 26, 41092 Sevilla, Spain
[3] Institut Català d'Ornitologia, Museu de Ciències Naturals de Barcelona, Pl. Leonardo da Vinci, 4-5, 08019 Barcelona, Spain
[4] Servei de Vigilància i Control de Plagues Urbanes, Agencia de Salud Pública de Barcelona, Pl. Lesseps, 1, 08023 Barcelona, Spain
*Corresponding author: tel: +34932309500; email: joan@icm.csic.es

Fishing activity generates high amounts of fishing discards, a predictable anthropogenic food subsidies used by seabirds. Although the use of discards by these predators has been well studied, there is a lack of knowledge about the ontogenetic differences in their use. We contributed to filling this gap for the yellow-legged gull (*Larus michahellis*), an opportunistic predator that extensively exploits anthropogenic food subsides. We investigated its foraging behaviour during the early breeding season deploying GPS devices on adults, immatures, and juveniles from the urban population of Barcelona (northwestern Mediterranean Sea) and examining the effect of fishing vessels on their spatial movements using a Vessel Monitoring System. The results revealed age-related differences in distribution and foraging behaviour at sea and an interaction with fishing vessels in this seabird. Age-related differences in behaviour were explained by the reproductive constraints of adults and the ontogenetic differences associated with lower foraging ability in immature and juvenile individuals. We did not find apparent preferences for a specific type of fishing vessel between ages. These results suggest that the reform of the Common Fisheries Policy might affect the entire population of this species, that could lead to an increase in the use of urban environments, increasing the conflicts with human activities.

Keywords: discards, fisheries interactions, foraging ecology, ontogenetic differences, opportunistic predators, urban marine ecology, yellow-legged gull

Introduction

In marine ecosystems, the impact of fisheries has changed the availability of trophic resources, affecting the population dynamics of marine predators (Grémillet *et al.*, 2018). The depletion of fishing stocks generally implies a negative effect on marine fauna. However, this anthropogenic activity also generates high amounts of fishing discards (around 9.1 million tonnes; Roda *et al.*, 2019), a predictable anthropogenic food subsidy extensively consumed by opportunistic seabirds (Oro *et al.*, 2013). In fact, some opportunistic seabirds such as different gull species have learned to exploit discards, adapting their foraging movements to fishing vessel activity patterns (Bartumeus *et al.*, 2010; Bécares *et al.*, 2015; Matos *et al.*, 2018; Ouled-Cheikh *et al.*, 2020) or linking reproductive success and population dynamics to anthropogenic food subsidies availability (Real *et al.*, 2017).

The yellow-legged gull (*Larus michahellis*) is a good example of an opportunistic seabird widely distributed throughout the Mediterranean region and making ample use of fishery discards (e.g. Ramos *et al.*, 2009; Lopezosa *et al.*, 2019; Calado *et al.*, 2021). Most populations of this gull species have exponentially grown over the last decades, in part due to their ability to exploit discards originating from fishing activity (Oro *et al.*, 2013). However, although the foraging ecology and the importance of anthropogenic food subsidies for the yellow-legged gulls has been relatively well studied (Ramos *et al.*, 2009; Méndez *et al.*, 2020), there is a clear lack of knowledge about the potential ontogenetic differences in the foraging ecology in this and other seabirds. Based on the optimal foraging theory, it is predicted that seabirds will minimize the time travelled between feeding grounds, maximizing time in more profitable feeding areas (Sthephens and Krebs, 1986), which could be associated with the presence of fishing discards (Cecere *et al.*, 2015; Tyson *et al.*, 2015). However, this optimal strategy requires a learning process during different age-stages. Because of that, when juvenile individuals begin to forage independently from their parents, they show less efficient movements than adults (de Grissac *et al.*, 2017; Carter *et al.*, 2019). In addition, in some seabirds, it has been observed that this lack of foraging skills is compensated by an increase in the effort of searching for food, which means more time dedicated to this activity and sometimes more distance travelled compared to adult individuals (Riotte-Lambert and Weimerskirch, 2013; de Grissac *et al.*, 2017). Another potential factor to consider is the possible intraspecific competition between adults and juveniles that force them to use alternative feeding grounds (Gutowsky *et al.*, 2014; de Grissac *et al.*, 2017).

The lack of ecological information on non-breeding individuals can lead to uncertainty in the consequences of new anthropogenic food subsides management measures at a population level, especially for problematic species such as the yellow-legged gull. A clear example is the reform of the

Received: 14 December 2021; **Revised:** 24 May 2022; **Accepted:** 3 June 2022
© The Author(s) 2022. Published by Oxford University Press on behalf of International Council for the Exploration of the Sea. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted reuse, distribution, and reproduction in any medium, provided the original work is properly cited.

Downloaded from https://academic.oup.com/icesjms/article/80/9/2405/6623969 by guest on 19 July 2024

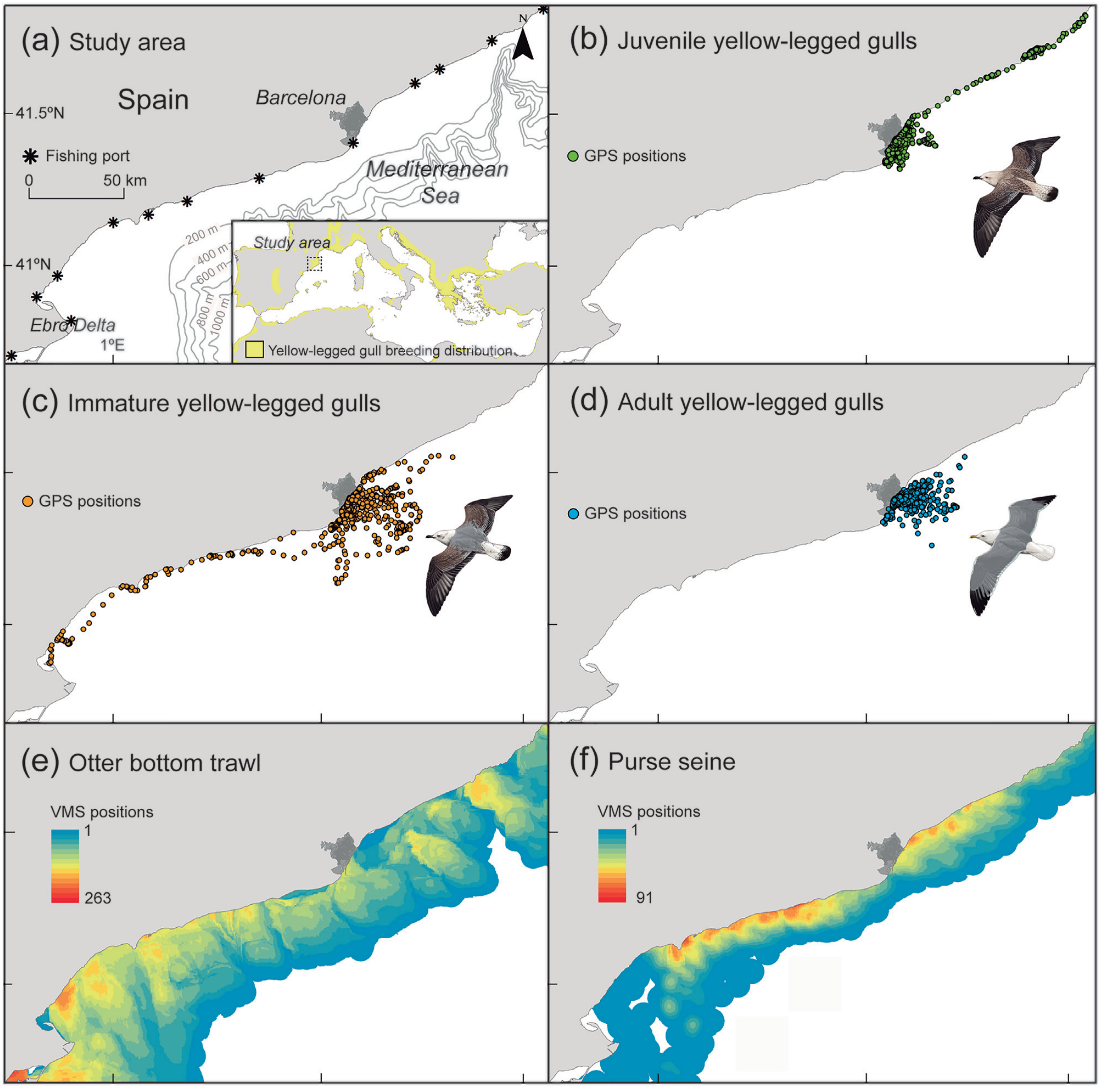

Figure 1. (a) Study area showing the locations of the fishing ports, the urban breeding area (Barcelona), and the breeding distribution of the yellow-legged gull in the Mediterranean Basin. At-sea spatial distribution of six juvenile (b), nine immature (c), and ten adult (d) GPS-tracked yellow-legged gulls from the urban population of Barcelona city, and the VMS-tracked otter bottom trawl (e) and purse seine (f) fishing vessels between March and May 2019. The drawings of yellow-legged gulls were made by Martí Franch.

Common Fisheries Policy, which requires the landing of fisheries discards to create a more sustainable fishery from an economic and environmental point of view (landings obligation included under Article 15 of the COM 1380/2013 that prohibits the discarding of species subject to catch limits). Although not implemented in the Mediterranean Sea, where the fishing industry generates an average of around 230,000 tonnes of discards per year of discards (Tsagarakis *et al.*, 2014), its application is expected to cause a drastic reduction in the availability of discards, affecting the feeding behaviour of the different species present in marine ecosystems (Sardà *et al.*, 2015), including the community of opportunistic seabirds (Bicknell *et al.*, 2013).

Here, we aim to investigate the foraging ecology of juvenile (1 year old), immature (2–3 years old), and adult (>4 years old) yellow-legged gulls to evaluate the potential age-related differences in (1) the spatial distribution and foraging behaviour at sea and (2) the spatial interaction with the fishing vessels present in their foraging areas. To study the foraging movements, we equipped juvenile, immature, and adult yellow-legged gulls inhabiting the urban ecosystem of the city of Barcelona (northwest Mediterranean Sea) with GPS loggers to assess which individuals might have used discard supplies from the fishing industry (Méndez *et al.*, 2020). To examine the interaction with fishing vessel movements, we took the GPS tracking data for yellow-legged gulls and we overlapped it with fishing vessel movement obtained by the Vessel Monitoring System (VMS) from all bottom trawlers and purse-seiners working in the foraging area used by gulls.

Material and Methods

Study area

The study was conducted in 2019 in the city of Barcelona (northeastern Iberian Peninsula, Spain, Figure 1a), a highly populated area (1.6 millions of people; IDESCAT, 2019). The yellow-legged gull urban population of Barcelona has increased in numbers from a few breeding pairs in the 1980s to around 250 breeding pairs today (García-Petit *et al.*, 1986; Anton *et al.*, 2017). Barcelona has several characteristics that make it attractive to this opportunistic species. The existence

Downloaded from https://academic.oup.com/icesjms/article/80/9/2405/6623969 by guest on 19 July 2024

of high buildings allows yellow-legged gulls to choose safe breeding places with low human disturbance. Moreover, the urban ecosystem of Barcelona surrounded by fishing ports, landfills, rivers, and agricultural areas provide easy-to-catch trophic resources to gulls (Méndez *et al.*, 2020; Carmona *et al.*, 2021). Similar to other places in the Mediterranean Sea, the marine ecosystems close to the city of Barcelona support a high level of fishing activity. For example, during 2019, the 224 otter bottom trawl vessels and 66 purse seine vessels working throughout the study area landed >23,000 tonnes of captures (IDESCAT, 2019). This fishing industry provides a large volume of fishing discards, including important food subsidies exploited by the yellow-legged gulls breeding in Barcelona (Méndez *et al.*, 2020).

GPS-tracking procedures

The study was carried out between March and May 2019, coinciding with the early breeding season of yellow-legged gulls in Barcelona (Méndez *et al.*, 2020). To investigate the foraging movements of the yellow-legged gulls, 10 juveniles (1 year old), 20 immatures (2 and 3 years old), and 15 breeding adults (>4 years old) were equipped with GPS devices (Cat-Log de Pethold Engineering LLC) configured with a frequency of 5-min data recording. All individuals were captured in a baited trap placed in an urban park in Barcelona close to the beach and their age was determined based on their plumage characteristics (following Arizaga *et al.*, 2019). In the case of adults, we also checked the presence of irrigated brood patch to be assigned as breeding adults (also confirmed with the detection of their nest based on the GPS data). GPS devices were attached using a wing harness, an attachment method used in large gulls such the yellow-legged gull (Thaxter *et al.*, 2014; Navarro *et al.*, 2017; Lameris *et al.*, 2018). The GPS device and harness weighed <2% of the body mass of the tracked-individuals (CatLog = 16 g; mean ± *SD* of tracked gulls = 1011 ± 164.65 g), less than the 3–5% body mass threshold suggested for seabirds (Phillips *et al.*, 2003; Passos *et al.*, 2010). Recorded GPS data were downloaded directly from the GPS device, so it was necessary to recapture all equipped gulls in the same baited trap. From the 45 equipped individuals, we were able to recapture six juvenile, nine immature, and ten adult yellow-legged gulls. All fieldwork was conducted in accordance with the Spanish and EU legislation on the protection of animals used for scientific purposes (REF: 56–678–2019).

GPS data analysis

To investigate the foraging behaviour of the 25 tracked gulls, we first calculated the proportion of positions at sea in relation to the total locations recorded by each tracked individual in both terrestrial and sea habitats, removing the erroneous GPS locations with speed >70 km). Main foraging areas were defined as the area encompassing 50, 75, and 95% isopleths of bivariate normal kernel analysis with ArcGIS10. We also estimated the type of behaviour associated with each remaining at-sea location by using Expectation-Maximization binary Clustering (EMbC; Garriga *et al.*, 2016). This method allows the classification of each location behaviour into four main categories: resting, intensive search, extensive search, and traveling. Then, we standardized the proportion of positions associated with each of the four behaviours for each individual in relation to the total GPS data recorded at sea.

Interaction between the movements of gulls and fishing vessels

To investigate the interactions between the spatial movements of yellow-legged gulls and the fishing vessels, we combined the spatial and temporal information at sea of each of the 25 GPS-tracked gulls with the movement data of all the otter bottom trawl and purse seine vessels present in the foraging area of gulls during the study period using VMS information (Spanish Government). VMS is a remote satellite positioning system that records the location of fishing vessels of >12 m length every 2 h. VMS data has been amply used to investigate seabird-fishery interactions (e.g. Granadeiro *et al.*, 2014; Sommerfeld *et al.*, 2016; Soriano-Redondo *et al.*, 2016). To examine the interactions between the vessels and the spatial movements of GPS-tracked gulls, we selected all gulls positions within 10 min before and after each VMS location and within a 5-km buffer area of influence around the VMS locations. For this, we used the software R 4.1.1 (R Core Team, 2021). This buffer area has been used in previous studies (Votier *et al.*, 2010; Sommerfeld *et al.*, 2016). Then, for each GPS-tracked gull, we calculated the proportion of positions associated with each type of fishing vessel (otter bottom trawl or purse seine) in relation to the total positions at-sea recorded.

Statistical analyses

Differences between juvenile, immature, and adult gulls related to the use of marine habitat, the type of behaviour at sea, the interaction with fishing vessels, and the potential differences between weekdays and weekends were tested using the non-parametric Permutational multivariate analysis of variance (PERMANOVA) tests (PRIMER-E v6 software, Anderson *et al.*, 2008) based on a Bray–Curtis distance matrix. Prior to these analyses, data were square-root transformed to minimize the impact of outliers. The method calculates a *pseudo-F* statistic, analogue to the traditional *F* statistic used in ANOVA tests, using permutation procedures to obtain the *p*-values (Anderson *et al.*, 2008).

Results

Foraging movements and behaviours of yellow-legged gull by age

All GPS-tracked gulls used the sea (Figure 1b-d and Supplementary Figures S1–S3; Table 1), but we found statistical differences in the proportion of locations at sea between ages ($pseudo\text{-}F_{2,23} = 3.88$, $p = 0.03$; Figure 2a), with the juveniles making a comparably higher use of the sea (Pair-wise tests, $p < 0.05$; Table 2, Figure 2a and Supplementary Figure S1). Regarding the distribution at sea, immatures reached marine areas up to 140 km south covering a feeding area of 2583 km ^{2} (UD50 = 74.14 km^2, UD75 = 176.27 km^2, and UD95 = 896.83 km^2), juveniles reached a distance of only 87 km north of Barcelona city covering a feeding area of 827.86 km^2 (UD50 = 23.26 km^2, UD75 = 53.91 km^2, and UD95 = 186.06 km^2), (Figure 1b and c), and adults reached a maximum distance of 32 km from Barcelona and were distributed only in the marine area close to the breeding area, covering a feeding area of 870.37 km^2 (UD50 = 36.56 km^2, UD75 = 106.56 km^2, and UD95 = 292.94 km^2) (Figure 1d).

In relation to foraging behaviour at sea, we found differences among behaviours ($pseudo\text{-}F_{3,99} = 0.59$, $p = 0.01$) and in the interaction age × behaviour ($pseudo\text{-}F_{6,99} = 0.59$, *p*

Downloaded from https://academic.oup.com/icesjms/article/80/9/2405/6623969 by guest on 19 July 2024

Table 1. Tracking details of the GPS deployments on juvenile (JU), immature (IM), and adult (AD) yellow-legged gulls from the urban population of Barcelona city during March and May 2019.

Individual	Age	Date of first GPS fix	Date of last GPS fix	Total duration (days)	Total locations	Total locations at sea
PXJH	JU	5/4/19	20/4/19	16	4 624	377
PXKU	JU	10/4/19	28/4/19	19	5 043	1470
PXLM	JU	6/4/19	14/4/19	9	3 131	720
PXLU	JU	11/4/19	14/4/19	4	1 994	53
PXMB	JU	10/4/19	27/4/19	18	4 864	1 166
PXML	JU	30/4/19	7/5/19	8	2 049	467
PXJU	IM	5/4/19	20/4/19	16	4 624	377
PXLN	IM	19/4/19	30/4/19	12	4 980	292
PYDP	IM	14/4/19	25/4/19	12	3 240	791
PXLH	IM	30/4/19	17/5/19	18	5 387	1 127
PXTF	IM	7/5/19	24/5/19	18	5 344	192
PYCU	IM	7/5/19	23/5/19	17	5 135	97
PYCX	IM	12/5/19	24/5/19	13	3 183	40
PYEP	IM	3/4/19	7/4/19	5	886	83
PYFW	IM	10/4/19	17/4/19	8	2 130	11
PBLZ	AD	9/5/19	30/5/19	22	843	72
PBMM	AD	11/3/19	29/5/19	80	1 911	48
PBSF	AD	30/4/19	15/5/19	16	4 338	246
PBWB	AD	3/5/19	29/5/19	27	1 210	20
PXJS	AD	16/5/19	30/5/19	15	926	33
PXMC	AD	29/4/19	31/5/19	33	1 553	77
PXXT	AD	23/4/19	31/5/19	39	1728	40
PXZT	AD	5/3/19	8/3/19	4	103	20
PXZY	AD	26/4/19	26/4/19	1	208	3
PZZC	AD	30/4/19	18/5/19	19	5074	302

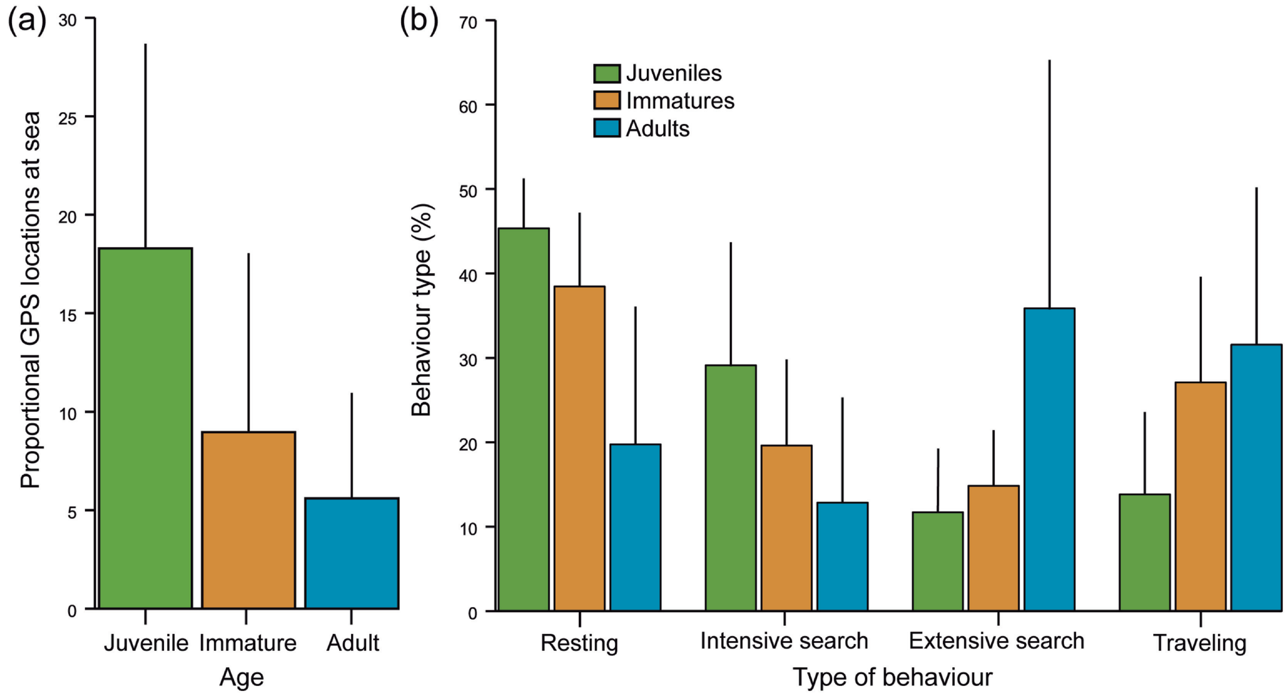

Figure 2. Mean and standard deviation of the percentage of (a) foraging locations at sea, and (b) behaviour type for six juvenile, nine immature, and ten adult yellow-legged gulls GPS-tracked from the urban population of Barcelona city between March and May 2019.

= 0.001) (Table 2, Figure 2b). In particular, pair-wise tests indicated that the number of positions associated with resting behaviour were higher in juveniles and immatures than in adults ($p < 0.05$; Figure 2b, Table 2). In the case of extensive search behaviour, we found that juveniles showed higher values than adults ($p < 0.05$), with no difference between immatures and the other two groups ($p > 0.05$; Figure 2b, Table 2). In the case of travelling and intensive search behaviours, juveniles showed lower values than adults and immatures (that did not differ between them, $p > 0.05$), respectively (Figure 2b. Table 2). Moreover, regarding to the differences between daylight and darkness hours, we only found differences in the travelling behaviour (Table 2). Specifically, in comparison with juveniles and immatures, adults spent lower and higher time travelling during daylight and darkness, respectively (Table 2, $p < 0.05$).

Downloaded from https://academic.oup.com/icesjms/article/80/9/2405/6623969 by guest on 19 July 2024

Table 2. Foraging behaviour descriptors (mean and standard deviation) and fishing vessel interactions of juvenile, immature, and adult GPS-tracked yellow-legged gulls from the urban population of Barcelona city between March and May 2019.

	Juveniles ($n = 6$)	Immatures ($n = 9$)	Adults ($n = 10$)
FORAGING AT SEA (%)			
Total locations at-sea	**18.3 ± 9.5$_a$**	**9.0 ± 8.6$_b$**	**5.6 ± 5.1$_b$**
During daylight	70.4 ± 24.4$_a$	74.1 ± 33.6$_a$	61.2 ± 27.1$_a$
During darkness	29.5 ± 24.5$_a$	25.9 ± 32.9$_a$	38.7 ± 26.8$_a$
BEHAVIOUR (%)			
Resting	**45.3 ± 5.9$_a$**	**38.5 ± 8.7$_a$**	**19.7 ± 16.3$_b$**
During daylight	68.7 ± 29.1$_a$	55.4 ± 42.7$_a$	26.0 ± 37.4$_a$
During darkness	31.2 ± 28.8$_a$	33.4 ± 38.6$_a$	53.9 ± 45.1$_a$
Intensive search	**29.1 ± 14.6$_a$**	**19.6 ± 10.2$_b$**	**12.8 ± 12.5$_b$**
During daylight	74.6 ± 19.7$_a$	58.8 ± 46.1$_a$	37.6 ± 37.1$_a$
During darkness	25.3 ± 19.5$_a$	18.8 ± 33.6$_a$	42.3 ± 38.5$_a$
Extensive search	**14.8 ± 7.5$_a$**	**14.8 ± 6.6$_{a,b}$**	**35.9 ± 29.4$_b$**
During daylight	75.9 ± 30.6$_a$	75.8 ± 34.5$_a$	70.4 ± 26.4$_a$
During darkness	24.1 ± 30.4$_a$	24.1 ± 33.7$_a$	29.5 ± 26.5$_a$
Travelling	**13.8 ± 9.8$_a$**	**27.1 ± 12.5$_b$**	**31.6 ± 18.6$_b$**
During daylight	**87.9 ± 9.6$_a$**	**84.3 ± 15.6$_a$**	**54.4 ± 27.8$_b$**
During darkness	**12.1 ± 9.7$_a$**	**15.6 ± 16.4$_a$**	**35.5 ± 23.8$_b$**
VESSEL INTERACTIONS (%)			
Otter–trawl interactions	31.7 ± 33.8	33.8 ± 35.1	4.7 ± 5.3
Purse–seine interactions	50.5 ± 60.3	17.4 ± 59.8	33.0 ± 58.4

In bold, the variables that showed significant differences based on PERMANOVA tests. The results of a *post-hoc* test are shown by the subscripts: for each variable—the means of species with the same letter were not significantly different.

Spatiotemporal interaction between gulls and vessels

Otter bottom trawl and purse seine vessels were distributed throughout the study area (Figure 1e and f). In the case of otter bottom trawl vessels, the higher fishing activity was found close to the coast, with high density values in the southern zone, near the Ebro Delta (Figure 1e). In contrast, the higher fishing activity of purse seine vessels was found in the central waters of the study area (Figure 1f).

We found that most of the GPS-tracked gulls interacted with fishing vessels, with no differences between ages in the use of a particular type of vessel (Table 2; among ages, *pseudo*-$F_{2,44} = 1.06$, $p = 0.35$; vessel type, *pseudo*-$F_{1,44}$) or in the interaction vessel type × age (*pseudo*-$F_{2,23} = 0.47$, $p = 0.62$).

When comparing weekdays vs. weekend, we found that immatures and adults used the sea habitat less proportion of time at sea during weekends than juveniles (*pseudo*-$F_{1,74} = 6.71$, $p = 0.01$; pair-wise tests, $p < 0.05$; Figure 3a). In the case of juveniles, they did not differ in their use of marine habitats between weekdays and weekends ($p < 0.05$; Figure 3a). Regarding the daily activity patterns, we found that during the night, associated with the period of purse seine vessel activity, adults were more active, followed by immatures and juveniles (Figure 3b). Close to sunrise, we can observe one peak, just when otter bottom trawl vessels began their fishing activity. After sunrise the activity decrease, especially in adults. We also showed a secondary peak 2–3 h before otter bottom trawl finished their fishing activity (Figure 3b).

Discussion

Here, we investigated the foraging behaviour of juvenile, immature, and adult yellow-legged gulls, including the potential effect of fishing vessel activity on their spatial movements at sea. Although the number of GPS-tracked individuals were low, the results revealed age-related differences in the use of marine habitat and in behavioural states associated with foraging locations. Moreover, we found that fishing activity affects the foraging behaviour of yellow-legged gull, but with apparently greater effects on immature and adult gulls, especially regarding daily activity patterns. This study provides new ecological information on how different subgroups of a population use the marine environment. Related to this, the elimination of fishing discards posed by the new reform of the European Union Fisheries Policy could distinctively affect this urban population of yellow-legged gulls.

Differences in foraging distribution and behaviour between ages

According to the optimal foraging theory, adult individuals have better knowledge of locations with a greater probability of obtaining food, consequently optimizing their foraging decisions (Sthephens and Krebs, 1986). As the study period was conducted during the incubation and chick-rearing period of the yellow-legged gull, breeding adults also have spatial constraints associated with the need to feed themselves and return to the nests located in the city to incubate or to provide food to their chicks (Méndez *et al.*, 2020). Therefore, adult seabirds are expected to optimize their foraging strategies by minimizing the distance colony-feeding ground and thus increasing foraging efficiency (Riotte-Lambert and Weimerskirch, 2013; Wakefield *et al.*, 2014). In our case, all of these aspects were reflected in the different foraging descriptors analysed.

For example, adults optimize their foraging time by minimizing the distance from the nest to their feeding grounds (Baert *et al.*, 2021), highly concentrated close to the city of Barcelona. However, in other yellow-legged gull breeding areas located in natural habitats, adults forage in more distant areas (e.g. Navarro *et al.*, 2017; Matos *et al.*, 2018), probably reflecting that opportunistic gulls efficiently exploit the resources close to their urban nests in cities (Méndez *et al.*, 2020; Spelt *et al.*, 2021). In contrast, juvenile and immature yellow-legged gulls, without the reproductive restriction of adults, reached locations far from the breeding colony (Baert *et al.*, 2021). This spatial segregation could also be a

Downloaded from https://academic.oup.com/icesjms/article/80/9/2405/6623969 by guest on 19 July 2024

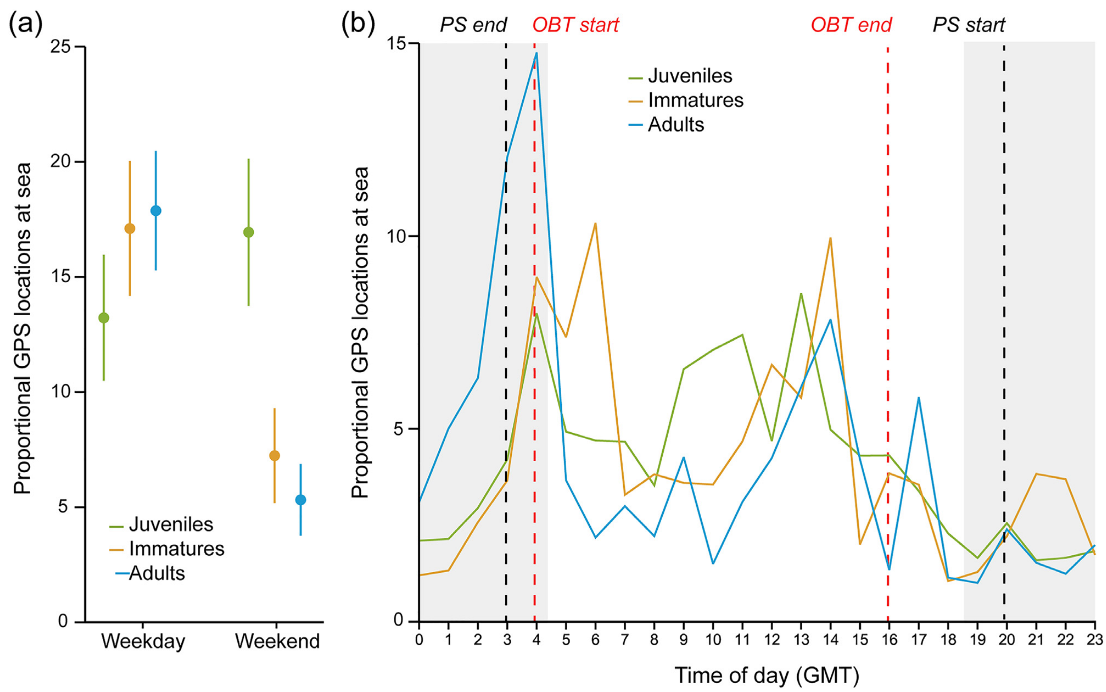

Figure 3. (a) Mean and standard error of the foraging locations at sea between weekdays and weekends, and (b) daily activity pattern at sea for six juvenile, nine immature, and ten adult yellow-legged gulls GPS-tracked from the urban population of Barcelona city between March and May 2019. The grey shaded area represents the night hours. The start and the end of the fishing activity of otter bottom trawl (OBT) and purse seine (PS) vessels are indicated with vertical dashed lines.

mechanism to reduce competition for food between ages, an ecological mechanism described in other seabirds (Gutowsky *et al.*, 2014; Phillips *et al.*, 2017). In fact, it has been suggested that the presence of spatial segregation between adults and juveniles/immatures is higher in seabird species where adults stay close to the colonies de Grissac *et al.*, 2016). Similarly, the fact that the main behaviour in adult yellow-legged gulls was the extensive search, indicated that adults were searching for food reducing the time invested and, thus, increasing their effectiveness in finding food due to a better knowledge of food location and availability (Riotte-Lambert and Weimerskirch, 2013).

In the case of juveniles, we showed that they spend more time in the marine habitat than older yellow-legged gulls. This result is probably a proxy for how juvenile individuals compensate for their lack of skills, investing more time foraging (Riotte-Lambert and Weimerskirch, 2013; de Grissac *et al.*, 2017). In fact, we found that juveniles showed more locations at sea with resting behaviour than adults. This result agrees with the results obtained by de Grissac *et al.* (2017) on juvenile individuals of wandering albatross (*Diomedea exulans*) using the same algorithm to estimate the behavioural state (Garriga *et al.*, 2016), and with the evidence that juveniles had lower foraging success than adults in different species of seabirds (Phillips *et al.*, 2017). Juvenile yellow-legged gulls have more positions associated with resting reflecting the comparatively higher energetic demands of adults that need to feed themselves and their chicks during the breeding period (de Grissac *et al.*, 2017). In juveniles, we also showed that the number of positions associated with intensive foraging was significantly higher than in adults. The high competition for food between ages could explain this difference (Catry *et al.*, 2004; de Grissac *et al.*, 2016). This is likely because adults fly faster (extensive foraging), detect their potential prey, feed quickly and leave. On the other hand, juveniles, having to compete with adults, immatures, and other species that also take advantage of marine resources, must wander more, mainly using an intensive foraging approach (Afán *et al.*, 2019).

Interactions between foraging movements and fishing vessels

It is well known that seabirds interact with fishing vessels to feed on their discards or on prey that some fishing gears concentrate on the surface (Bartumeus *et al.*, 2010; Bécares *et al.*, 2015; Ouled-Cheikh *et al.*, 2020). For the yellow-legged gull, overall, we found that the interactions with otter bottom and purse seine vessels were lower than expected according to the high proportion of fishing discards of this opportunistic gull in this colony (Méndez *et al.*, 2020) and in other populations (e.g. Ramos *et al.*, 2009; Lopezosa *et al.*, 2019). Our methodology likely underestimated the real use of fishing vessels when this species is foraging at sea because we only considered vessels >12 m in length, which are the only ones with a VMS system, underestimating the potential use of the artisanal fleet in the study area, a type of fishing vessel that attracts seabirds, especially when trawlers are not active (Laneri *et al.*, 2010). Also, although we expected that yellow-legged gulls to show a preference for otter bottom trawl over purse seine vessels similar to other Mediterranean seabirds such as the Audouin's gull (*Ichthyaetus audouinii*) and Cory's shearwater (*Calonectris diomedea*) (Soriano-Redondo *et al.*, 2016; Ouled-Cheikh *et al.*, 2020), we did not find any preference between the two types of fishing vessels. Given that trawlers work during the day and purse seiners at night, the absence of significant differences in the use of these vessels indicates that yellow-legged gulls also visit the sea during the night. This result is

Downloaded from https://academic.oup.com/icesjms/article/80/9/2405/6623969 by guest on 19 July 2024

surprising because the yellow-legged gull, unlike other gulls such as Audouin's gull (Arcos *et al*., 2001), is not considered a nocturnal species (Parra-Torres *et al*., 2020). The use of spotlights by purse seiners in combination with the short distance from the coast at which these vessels operate in the central area could favour the use of these fishing vessels (Arcos and Oro, 2002). This behaviour also may explain the presence of pelagic fish species such European anchovy (*Engraulis encrasicolus*), European sardine (*Sardine pilchardus*), and horse mackerel (*Trachurus trachurus*) in the diet of yellow-legged gulls present in Barcelona (Méndez *et al*., 2020).

Contrary to our expectations, the data did not show that immature and juvenile yellow-legged gulls interact less with fishing boats compared to adults, indicating that they also exploit the resource generated by this human activity. In the case of juveniles, we found that they use the marine environment regardless of whether the fishing vessels were working (workdays) or not (weekend). Based on these results, we expect that when the Common Fisheries Policy reform is applied, eliminating these food subsidies for seabirds and other opportunistic marine predators, it will also affect yellow-legged gulls at a population level. In addition to the different consequences of the discard ban suggested by Bicknell *et al*. (2013), for the urban population of Barcelona, we might expect an increase in the presence of yellow-legged gulls, independent of their age, in urban habitats. This could lead to an increase in the predation of urban birds such as pigeons (*Columba livia)* or invasive monk parakeets (*Myiopsitta monachus*), two important prey for yellow-legged gull in this urban area (Méndez *et al*., 2020), or to a possible increase in their presence in terrestrial habitats (Ouled-Cheikh *et al*., 2021). This shift towards terrestrial resources could lead to two main responses. This potential change in foraging behaviour could increase conflicts with human activities, especially in urban areas (Bicknell *et al*., 2013), causing problems such as damage to urban structures, noise, or the potential transmission of pathogens (Belant, 1997; Vidal *et al*., 1998; Vergara *et al*., 2017). Moreover, if the nutrients supply from these terrestrial and urban sources is insufficient to maintain the population (Sotillo *et al*., 2019), we could observe a population decline until they adapt to the new situation (Ramos *et al*., 2011). For this reason, we suggest the long-term monitoring of the population dynamics and foraging behaviour of opportunistic gulls inhabiting urban environments to investigate the potential repercussions of these new regulations of the Common Fisheries Policy in the European Union.

Conclusions

In this study, we quantified age-related differences in the spatial distribution and foraging behaviour at sea and the interaction with fishing vessels of an opportunistic seabird, the yellow-legged gull. The differences in the foraging behaviour between ages were mainly explained both by the reproductive constraints of adults and the ontogenetic differences associated with the lower foraging ability of immature and juvenile individuals. In the case of the effect of fishing activity on the foraging behaviour of yellow-legged gulls, we did not find any preference for a specific type of fishing vessel (otter bottom trawl or purse seine). On the other hand, the similar association between fishing vessel activity and spatial distribution at sea of juvenile, immature, and adult gulls suggest that the reform of the Common Fisheries Policy probably will have similar effects across the entire population, causing a potential increase in the use of urban and terrestrial environments. This situation could lead to an increase in conflicts between human activities and the urban populations of opportunistic gulls.

Aknowledgements

Thanks to the staff of the Zoo of Barcelona, especially Pablo Cermeño and Camilo Iriondo, for their help in the trapping procedures. Jacob González-Solís, David March, Richard A. Phillips (Associate Editor) and two anonymous reviewers provided very useful suggestions on a previous draft of the paper. Secretaría General de Pesca Marítima of Ministerio de Agricultura y Pesca of the Spanish Government provided the Vessel Monitoring System data. This work acknowledges the "Severo Ochoa Centre of Excellence" accreditation (CEX2019-000928-S). All fieldwork was conducted in accordance with the Spanish and EU legislation on the protection of animals used for scientific purposes.

Supplementary Data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

Data availability statement

The data underlying this article will be shared upon reasonable request to the corresponding author.

Author contributions

JN, TM, and RA designed the analysis. JN, MG, IA, and JAG performed the analysis and led the writing of the manuscript. All authors helped conceive ideas, contributed critically to the drafts, and gave final approval for publication.

Funding

This study is part of the BCN-Gulls project funded by the Barcelona Zoo Foundation and the Ramón y Cajal project (RYC-2015–17809) led by JN and the Bachelor Thesis of MG (funded with a JAE-SOMdM21-80, CSIC).

Conflict of interest

The authors declare no conflict of interest.

References

Afán, I., Navarro, J., Grémillet, D., Coll, M., Forero, M. G. 2019. Maiden voyage into death: are fisheries affecting seabird juvenile survival during the first days at sea? Royal Society Open Science, 6: 181151.

Anderson, M. J., Gorley, R. N., Clarke, K. R. 2008. PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods. Plymouth. UK.

Anton, M., Herrando, S., , Garcia, D., Ferrer, , X., Cebrian, R. 2017. Atles dels ocells nidificants de Barcelona. Ajuntament de Barcelona / ICO / UB / Zoo. Barcelona, Barcelona, Spain.

Arcos, J. M., Oro, D. 2002. Significance of nocturnal purse seine fisheries for seabirds: a case study off the Ebro delta (NW Mediterranean). Marine Biology, 141: 277–286.

Downloaded from https://academic.oup.com/icesjms/article/80/9/2405/6623969 by guest on 19 July 2024

Arcos, J. M., Oro, D., Sol, D. 2001. Competition between the yellow-legged gull *Larus cachinnans* and Audouin's gull *Larus audouinii* associated with commercial fishing vessels: the influence of season and fishing fleet. Marine Biology, 139: 807–816.

Arizaga, J., Herrero, A., Aldalur, A. 2019. Seasonal pattern of plumage colour in Yellow-legged gulls at Bay of Biscay, Spain. Dutch Birding, 41: 166–174.

Baert, J. M., Stienen, E. W. M., Verbruggen, F., Van de Weghe, N., Lens, L., Müller, W. 2021. Context-dependent specialisation drives temporal dynamics in intra- and inter-individual variation in foraging behaviour within a generalist bird population. Oikos, 130: 1272–1283.

Bartumeus, F., Giuggioli, L., Louzao, M., Bretagnolle, V., Oro, D., Levin, S. A. 2010. Fishery discards impact on seabird movement patterns at regional scales. Current Biology, 20: 215–222.

Bécares, J., García-Tarrasón, M., Villero, D., Bateman, S., Jover, L., García-Matarranz, V., Sanpera, C., *et al*.., 2015. Modelling terrestrial and marine foraging habitats in breeding Audouin's gulls *Larus audouinii*: timing matters. PLoS One, 10: e0120799.

Belant, J. L. 1997. Gulls in urban environments: landscape-level management to reduce conflict. Landscape and Urban Planning, 38: 245–258.

Bicknell, A. W. J., Oro, D., Camphuysen, K. C. J., Votier, S. C. 2013. Potential consequences of discard reform for seabird communities. Journal of Applied Ecology, 50: 649–658.

Calado, J., Veríssimo, S., Paiva, V., Ramos, R., Vaz, P., Matos, D., Pereira, J., Lopes, C., *et al*. 2021. Influence of fisheries on the spatio-temporal feeding ecology of gulls along the western Iberian Coast. Marine Ecology Progress Series, 661: 187–201.

Carmona, M., Aymí, R., Navarro, J. 2021. Importance of predictable anthropogenic food subsidies for an opportunistic gull inhabiting urban ecosystems. European Journal of Wildlife Research, 67: 9.

Carter, M. I. D., McClintock, B. T., Embling, C. B., Bennett, K. A., Thompson, D., Russell, D. J. F. 2020. From pup to predator: generalized hidden Markov models reveal rapid development of movement strategies in a naïve long-lived vertebrate. Oikos, 129: 630–642.

Catry, P., Campos, A., Almada, V., Cresswell, W. 2004. Winter segregation of migrant European Robins *Erithacus rubecula* in relation to sex, age and size. Journal of Avian Biology, 35: 204–209.

Cecere, J. G., Catoni, C., Gaibani, G., Geraldes, P., Celada, C., Imperio, S. 2015. Commercial fisheries, inter-colony competition and sea depth affect foraging location of breeding Scopoli's Shearwaters *Calonectris diomedea*. Ibis, 157: 284–298.

de Grissac, S., Bartumeus, F., Cox, S. L., Weimerskirch, H. 2017. Early-life foraging: behavioral responses of newly fledged albatrosses to environmental conditions. Ecology and Evolution, 7: 6766–6778.

de Grissac, S., Börger, L., Guitteaud, A., Weimerskirch, H. 2016. Contrasting movement strategies among juvenile albatrosses and petrels. Scientific Reports, 6: 1–12.

Roda, M.A.P., Gilman, E., Huntington, T., Kennelly, S. J., Suuronen, P., Chaloupka, M., Medley, P. 2019. A third assessment of global marine fisheries discards, FAO Fisheries and Aquaculture Technical Paper No. 633. FAO , Rome, Italy.

García-Petit, J., Martí, M., Tomàs, X. 1986. Colonització de la ciutat de Barcelona pel gavià argentat (*Laurus cachinnans*). Miscel·lània Zoològica, 10: 401–403.

Garriga, J., Palmer, J. R. B., Oltra, A., Bartumeus, F. 2016. Expectation-maximization binary clustering for behavioural annotation. PLoS One, 11: e0151984.

Granadeiro, J. P., Brickle, P., Catry, P. 2014. Do individual seabirds specialize in fisheries' waste? The case of black-browed albatrosses foraging over the Patagonian Shelf. Animal Conservation, 17: 19–26.

Grémillet, D., Ponchon, A., Paleczny, M., Palomares, M. L. D., Karpouzi, V., Pauly, D. 2018. Persisting worldwide seabird-fishery competition despite seabird community decline. Current Biology, 28: 4009–4013.

Gutowsky, S. E., Tremblay, Y., Kappes, M. A., Flint, E. N., Klavitter, J., Laniawe, L., Costa, D. P., *et al*.., 2014. Divergent post-breeding distribution and habitat associations of fledgling and adult black-footed albatrosses *Phoebastria nigripes* in the North Pacific. Ibis, 156: 60–72.

Idescat.2019. Anuari estadístic de catalunya. Pesca. Institut d'Estadística de Catalunya, Barcelona. https://www.idescat.cat/pub/?id=aec&n=468

Lameris, T. K., Müskens, G. J. D. M., Kölzsch, A., Dokter, A. M., Van der Jeugd, H. P., Nolet, B. A. 2018. Effects of harness-attached tracking devices on survival, migration, and reproduction in three species of migratory waterfowl. Animal Biotelemetry, 6: 1–8.

Laneri, K., Louzao, M., Martínez-Abraín, A., Arcos, J. M., Belda, E. J., Guallart, J., Sánchez, A., *et al*..2010. Trawling regime influences longline seabird bycatch in the Mediterranean: new insights from a small-scale fishery. Marine Ecology Progress Series, 420: 241–252.

Lopezosa, P., Forero, M. G., Ramírez, F., Navarro, J. 2019. Individuals within populations: no evidences of individual specialization in the trophic habits of an opportunistic predator. Estuarine, Coastal and Shelf Science 229: 106427.

Matos, D. M., Ramos, J. A., Calado, J. G., Ceia, F. R., Hey, J., Paiva, V. H. 2018. How fishing intensity affects the spatial and trophic ecology of two gull species breeding in sympatry. ICES Journal of Marine Science, 75: 1949–1964.

Méndez, A., Montalvo, T., Aymí, R., Carmona, M., Figuerola, J., Navarro, J. 2020. Adapting to urban ecosystems: unravelling the foraging ecology of an opportunistic predator living in cities. Urban Ecosystems, 23: 1117–1126.

Navarro, J., Grémillet, D., Ramirez, F. J., Afán, I., Bouten, W., Forero, M. G. 2017. Shifting individual habitat specialization of a successful predator living in anthropogenic landscapes. Marine Ecology Progress Series, 578: 243–251.

Oro, D., Genovart, M., Tavecchia, G., Fowler, M. S., Martínez-Abraín, A. 2013. Ecological and evolutionary implications of food subsidies from humans. Ecology Letters, 16: 1501–1514.

Ouled-Cheikh, J., Morera-Pujol, V., Bahillo, Á., Ramírez, F., Cerdà-Cuéllar, M., Ramos, R. 2021. Foraging in the anthropocene: feeding plasticity of an opportunistic predator revealed by long term monitoring. Ecological Indicators, 129: 107943.

Ouled-Cheikh, J., Sanpera, C., Bécares, J., Arcos, J. M., Carrasco, J. L., Ramírez, F. 2020. Spatiotemporal analyses of tracking data reveal fine-scale, daily cycles in seabird–fisheries interactions. ICES Journal of Marine Science, 77: 2508–2517.

Parra-Torres, Y., Ramírez, F., Afán, I., Aguzzi, J., Bouten, W., Forero, M. G., Navarro, J. 2020. Behavioral rhythms of an opportunistic predator living in anthropogenic landscapes. Movement Ecology, 8: 17.

Passos, C., Navarro, J., Giudici, A., González-Solís, J. 2010. Effects of extra mass on the pelagic behavior of a seabird. The Auk, 127: 100–107.

Phillips, R. A., Lewis, S., González-Solís, J., Daunt, F. 2017. Causes and consequences of individual variability and specialization in foraging and migration strategies of seabirds. Marine Ecology Progress Series, 578:117–150.

Phillips, R. A., Xavier, J. C., Croxall, J. P. 2003. Effects of satellite transmitters on albatrosses and petrels. The Auk, 120: 1082–1090.

Ramos, R., Ramírez, F., Carrasco, J. L., Jover, L. 2011. Insights into the spatiotemporal component of feeding ecology: an isotopic approach for conservation management sciences. Diversity and Distributions, 17: 338–349.

Ramos, R., Ramírez, F., Sanpera, C., Jover, L., Ruiz, X. 2009. Diet of yellow-legged gull (*Larus michahellis*) chicks along the spanish western Mediterranean Coast: the relevance of refuse dumps. Journal of Ornithology, 150: 265–272.

Real, E., Oro, D., Martínez-Abraín, A., Igual, J. M., Bertolero, A., Bosch, M., Tavecchia, G. 2017. Predictable anthropogenic food subsidies, density-dependence and socio-economic factors influence

Downloaded from https://academic.oup.com/icesjms/article/80/9/2405/6623969 by guest on 19 July 2024

breeding investment in a generalist seabird. Journal of Avian Biology, 48: 1462–1470.

Riotte-Lambert, L., Weimerskirch, H. 2013. Do naive juvenile seabirds forage differently from adults? Proceedings of the Royal Society B: Biological Sciences, 280: 20131434.

Sardà, F., Coll, M., Heymans, J. J., Stergiou, K. I. 2015. Overlooked impacts and challenges of the new European discard ban. Fish and Fisheries, 16: 175–180.

Sommerfeld, J., Mendel, B., Fock, H. O., Garthe, S. 2016. Combining bird-borne tracking and vessel monitoring system data to assess discard use by a scavenging marine predator, the lesser black-backed gull *Larus fuscus*. Marine Biology, 163: 116.

Soriano-Redondo, A., Cortés, V., Reyes-González, J. M., Guallar, S., Bécares, J., Rodríguez, B., Arcos, J. M., *et al*., 2016. Relative abundance and distribution of fisheries influence risk of seabird bycatch. Scientific Reports, 6: 1–8.

Sotillo, A., Baert, J. M., Müller, W., Stienen, E. W. M., Soares, A. M. V. M., Lens, L. 2019. Recently-adopted foraging strategies constrain early chick development in a coastal breeding gull. PeerJ, 7: e7250.

Spelt, A., Soutar, O., Williamson, C., Memmott, J., Shamoun-Baranes, J., Rock, P., Windsor, S. 2021. Urban gulls adapt foraging schedule to human-activity patterns. Ibis, 163: 274–282.

Sthephens, D. W., Krebs, J. R. 1986. Foraging Theory, 1. Princeton University Press, Princeton, NJ.

Thaxter, C. B., Ross-Smith, V. H., Clark, J. A., Clark, N. A., Conway, G. J., Marsh, M., Leat, E. H. K., *et al*., 2014. A trial of three harness attachment methods and their suitability for long-term use on lesser black-backed gulls and great skuas. Ringing & Migration, 29: 65–76.

Tsagarakis, K., Palialexis, A., Vassilopoulou, V. 2014. Mediterranean fishery discards: review of the existing knowledge. Encyclopedia of Environment and Society, 71: 1219–1234.

Tyson, C., Shamoun-Baranes, J., van Loon, E. E., Camphuysen, K. C. J., Hintzen, N. T. 2015. Individual specialization on fishery discards by lesser black-backed gulls (*Larus fuscus*). ICES Journal of Marine Science, 72: 1882–1891.

Vergara, A., Pitart, C., Montalvo, T., Roca, I., Sabaté, S., Hurtado, J. C., Planell, R., *et al*., 2017. Prevalence of extended-spectrum-β-lactamase- and/or carbapenemase-producing escherichia coli isolated from yellow-legged gulls from Barcelona, Spain. Antimicrobial Agents and Chemotherapy, 61: e02071–16.

Vidal, E., Medail, F., Tatoni, T. 1998.Is the yellow-legged gull a superabundant bird species in the Mediterranean? Impact on fauna and flora, conservation measures and research priorities. Biodiversity and Conservation, 7: 1013–1026.

Votier, S. C., Bearhop, S., Witt, M. J., Inger, R., Thompson, D., Newton, J. 2010. Individual responses of seabirds to commercial fisheries revealed using GPS tracking, stable isotopes and vessel monitoring systems. Journal of Applied Ecology, 47: 487–497.

Wakefield, E. D., Phillips, R. A., Matthiopoulos, J. 2014. Habitat-mediated population limitation in a colonial central-place forager: the sky is not the limit for the black-browed albatross. Proceedings of the Royal Society B: Biological Sciences, 281: 20132883.

Handling Editor: Richard Phillips

Downloaded from https://academic.oup.com/icesjms/article/80/9/2405/6623969 by guest on 19 July 2024