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**Foraging movements of Audouin's gull (*Larus audouinii*) in the Ebro Delta, NW
Mediterranean: A preliminary satellite-tracking study**

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ABSTRACT

Knowing the foraging strategies of marine predators is essential to understand the intrinsic factors controlling their distribution, abundance and their ecological function within the marine ecosystem. Here, we investigated for the first time the foraging movements and activity patterns of Audouin's gull *Larus audouinii* by using satellite-tracking data from eight breeding adults in the main colony of the species worldwide (Ebro Delta, NW Mediterranean). Tagged gulls foraged in the marine area close to the breeding colony (62% of foraging locations) and in the terrestrial area of the Ebro Delta (mainly rice fields; 38% of foraging locations). The foraging activity patterns changed significantly throughout the day; lower from dusk through the first half of the night (19-1 h; 32% of active locations) and higher during the rest of the day (1-19 h; $75.5 \pm 4.3\%$ of active locations). These results confirm the foraging plasticity of this seabird and, based on previous information about the dietary habits of this species, we hypothesize how its time-dependent activity patterns and habitat use could be associated with variations in the availability of marine food resources (e.g. diel vertical migrations of pelagic fish) and the exploitation of terrestrial resources (e.g. American crayfish *Procambarus clarkii*).

Keywords: Ebro Delta, foraging activity, foraging distribution, habitat use, marine birds, marine habitat, Mediterranean Sea, rice fields,

1. Introduction

An important issue in the feeding ecology of marine predators is the degree of plasticity of their foraging behaviour. In general, specialist predators are constrained to forage on a specific habitat and time of day determined by a specific prey availability (Futuyma and Moreno, 1988; Krebs and Davies, 1993; Julliard et al., 2006). Under changing conditions of prey availability, specialists are able to adapt their foraging strategy by extending foraging range or time spent foraging (e.g. Oro et al., 1997; Lewis et al., 2001; Schwemmer and Garthe, 2008). By contrast, generalist predators have the ability to exploit different trophic resources and, consequently, they present higher plasticity in their foraging strategies (Krebs and Davies, 1993; Boyd et al., 2006; Julliard et al., 2006). This opportunistic behaviour allows generalists to modify their foraging strategies (i.e. exploited habitat, range or temporal patterns) according, for instance, to the varying degree of competition for food. Indeed, the foraging plasticity of marine predators has allowed these organisms to benefit from anthropogenic food resources (e.g. fisheries discards, refuse dumps or introduced prey species; Tablado et al., 2010; Ramos et al., 2011; Wagner and Boersma, 2011).

Amongst marine predators, the Audouin's gull *Larus audouinii* is a good example of an opportunist species that exhibits clear plasticity in its diet habits. This Mediterranean endemic species exploits small pelagic fish (their main prey, see Oro 1998 and references therein), but also alternative anthropogenic resources such as demersal or benthonic fish from fisheries discards or invasive freshwater crabs from terrestrial habitat (Oro et al., 1996a; Oro and Ruiz, 1997; Oro et al., 1999; Navarro et al., 2010). This opportunistic behaviour is especially relevant in breeding populations located in areas where diverse trophic resources are highly available (e.g. Oro and Ruiz, 1997; Oro

et al., 1999; Navarro et al., 2010), which is the case of the breeding population located in the Ebro Delta (Fig.1. NW Mediterranean). This colony holds around 12000-13000 breeding pairs of Audouin's gull, ca. 65% of the total world population (Oro et al., 2009). The marine ecosystem of the Ebro Delta is one of the most important fishing grounds in the Mediterranean Sea, resulting in one of the largest fishing fleets in this region, which generates a high quantity of fisheries discards (Coll et al., 2008). Moreover, freshwater resources such as the invasive American crayfish *Procambarus clarkii* in the rice fields of the Ebro Delta are abundant and easily available (Gutierrez-Yurrita et al., 1999), providing an alternative and proficient trophic resource for the species (Oro et al., 1996b; Longoni, 2010; Navarro et al., 2010).

Although the diet habits of the Audouin's gull are well known (e.g. Oro et al., 1997; Pedrocchi et al., 2002; Sanpera et al., 2007; Navarro et al. 2010), detailed information on the foraging movements is biased towards studies based on ship surveys (e.g. Abelló and Oro, 1998; Arcos et al., 2001; Abelló et al., 2003), which are strongly biased by the influence of fishery discards and underestimate the importance of land habitat utilization. The only previous telemetric study (radio-tracking) already pointed to the apparent importance of the terrestrial habitat for the breeding population of the Ebro Delta colony (Mañosa et al., 2004).

Here, we present preliminary results of the first satellite-tracking study of Audouin's gull during the breeding season in its largest breeding colony (Ebro Delta). This paper aims to quantify the foraging range of Audouin's gull, evaluate the habitat utilization of marine and terrestrial areas and identify the temporal patterns of the foraging activity of the species. Based on previous information about the dietary habits of this species, we also hypothesize how the observed foraging movements could be attributed to the

exploitation of different trophic resources in the Ebro Delta marine and terrestrial ecosystems.

2. Material and methods

2.1. Fieldwork procedures

The study was carried out at the natural reserve of Punta de la Banya in the Ebro Delta Natural Park, North Western Mediterranean Sea (Fig. 1, 40°33'N, 0°39'E). Punta de la Banya is a flat sandy peninsula of 2,514 ha, partially occupied by saltworks and connected to extensive rice field areas (20,000 ha) by a 5 km-long narrow sand bar. To examine the foraging activity, we satellite-tracked 8 breeding birds (4 males and 4 females) using battery powered “Platform Transmitter Terminals” (PTTs; North Star Science and Technology, LLC) during the chick-rearing period (May) of 2006 (Table 1). We captured all birds on the nest by using a drop trap (Mills and Ryder, 1979) during late incubation to reduce the risk of desertion. Once trapped, each individual was sexed, weighed, ringed and tagged with a PTT. The attached PTTs weighed 20 g and were programmed to be active in a 6 h on/5 h off duty cycle to get information on the foraging locations during one month. The PTT was fixed to the mid-dorsal feathers of the mantle using Tesa tape (Wilson et al., 1997). With this method the PTT falls off after one month without the necessity to recapture the instrumented bird. The entire transmitter equipment represented between 3-4% of the Audouin’s gull’s body mass, so the potential effects of an additional weight on the gull’s movement were minimized (e.g. Phillips et al., 2003; Passos et al., 2010).

2.2. Satellite-tracking data and statistical analyses

Data on the position of each PTT were obtained from ARGOS system (CLS, Toulouse, France) and imported to ArcView 3.2 (ESRI) using the Argos Tool extension (Potapov and Dubinin, 2005). Each position was classified according to its estimated error: Type 0 (>1000 m), Type 1 (350-1000 m), Type 2 (150-350 m), Type 3 (0-150 m), and Types A and B (without an estimated error) (ARGOS, 2006). Initial data filtering involved calculating velocities between successive satellite locations, and rejecting those for which the velocity exceeded a threshold of $50 \text{ m}\cdot\text{s}^{-1}$, the maximum velocity described for this species (Rosén and Hedenström, 2001). By this procedure, up to 8 % of the locations were filtered; all of them from the low-quality accuracy class “B”.

To gain insight into the foraging activity of the tagged Audouin’s gulls we sorted the locations into three classes, according to their spatial position. PTT locations inside the “Punta de la Banya” peninsula or within the first kilometer around it were classified into the “colony locations” group. In contrast, the locations outside the colony and the first kilometer around it were “foraging locations” (we assumed that the birds were feeding to recover the body condition lost during the incubation bout). Finally, we calculated the 95% fixed-kernel estimates of the foraging area and the maximum foraging distance from the colony.

We employed logistic regression – a generalized linear model (GLM) – to test the foraging activity and habitat use. First, we tested a model with the proportion of foraging locations as the dependent variable, and we selected as the explanatory variable the “time of day” -categorized in 6-hour intervals (1-7 h; 7-13 h; 13-19 h; 19-1 h)- with the 7-13 h interval as the reference level. Then, we analysed habitat use by testing the effect of the explanatory variable “time of day” on the dependent variable

“terrestrial vs. marine proportion of foraging locations”. The analyses were carried out using R software (R Development Core Team, 2008), calling the “glm” function with binomial error distribution and its default logit link function. A likelihood ratio test was used to compare the resulting model with the null model (without any variable) and to assess the significance of the explanatory variable “time of day”.

3. Results

We obtained a total of 89 filtered PTT locations spanning a period of 13 consecutive days. One of the eight PTTs failed to give any location probably due to a battery failure, and the performance of the remaining PTTs was heterogeneous (see Table 1). Due to sample size limitations individual variability was not included in the analysis, but the movements of one of the tracked individuals is shown in Figure 2 to illustrate the general pattern of the foraging movements.

The foraging area covered by the Audouin’s gulls was 5400 km² (95% fixed-kernel density estimate), covering both the marine area of the Ebro Delta (ca. 3300 km²) and the terrestrial area (ca. 2100 km²) (Fig. 1c). The maximum foraging distance covered ranged from 20.5 to 81.7 km (mean \pm sd = 51.5 \pm 24.3 km) and was similar for both marine and terrestrial locations (T-Student test, T = 1.44, df = 56, p = 0.15).

The foraging activity changed significantly over the course of the day (Likelihood Ratio Test, $\chi^2 = 13.79$, df = 3, p = 0.003). Tagged gulls were more active at 7-13 h (78.1%), at 1-7 h (77.8% of the total locations in this period, p = 0.65), and 13-19h (70.6%, p = 0.56), all of them significantly different from the 19-1 h interval (31.8%, p = 0.001), i.e., the foraging activity diminished during the first half of the night (Fig. 3b). Moreover, we found that the proportion of foraging locations in marine vs. terrestrial

habitats changed during the day. Although the time of day was not significant as a global explanatory variable, the model indicated a significant difference between the 13-19 h interval and the reference level 7-13 h ($p= 0.04$) (Fig. 3c). Between 13h and 19 h, Audouin's gulls foraged mainly in terrestrial (41%) rather than in marine habitat (29%); during the rest of the day, they foraged mainly in marine rather than terrestrial habitat (1-7h: 50% marine, 28% terrestrial habitat; 7-13h: 59% marine, 19% terrestrial habitat; 19-1h: 23% marine, 9% terrestrial habitat)(Fig. 3a).

4. Discussion

Satellite-tracked Audouin's gulls covered a foraging area that ranges 80 km, spanning both marine and terrestrial habitats. It has been widely described previously that breeding Audouin's gulls cover large ranges when foraging. There are records of individuals foraging at 70 to 150 km from the breeding colony during the breeding season (Baccetti et al., 2000; Mañosa et al., 2004), and data from vessel counts suggest that individuals forage during the day and night even further offshore (Abelló and Oro, 1998; Arcos and Oro, 1996). However, the species' terrestrial foraging movements had been scarcely described (Ruiz et al., 1996; Mañosa et al., 2004).

It is well documented that Audouin's gulls forage during the night in marine habitats preying on small pelagic fish and exploiting discards provided by nocturnal fisheries (e.g. Witt et al. 1981; Mañosa et al. 2004; Arcos et al., 2008). However, our results highlight that the species' nocturnal activity is not homogeneous throughout the night (see Fig.3). Satellite-tracked gulls were mainly located in the breeding colony during the hours before and after dusk (19-1 h). In the period after midnight to dawn (1-7 h) they increased their foraging activity, which then remained constant and high during the

day. These results, coupled with the nocturnal arrival and departure times from the breeding colony described in Mañosa et al. (2004), confirm a peak of activity between midnight and dawn. Attendance to purse seiners during the night is considered a strategy that is only significant during trawling moratorium and winter periods (Arcos and Oro, 2002), neither of which were covered during our study; therefore, the individuals located at sea during the night were probably feeding on small pelagic fish. Accordingly, the nocturnal foraging habits of the Audouin's gull would still rely on the capture of small pelagic fish (Witt et al., 1981; Oro, 1998), a resource that might not be available throughout the night, but only in the hours before dawn due to the diel vertical migration of the shoals (Blaxter and Hunter, 1982; Oro, 1998).

With regard to diurnal activity, tagged birds showed a high foraging activity with an unexpected constant presence in terrestrial habitats (generally rice fields or wetlands) in addition to the expected presence in marine habitat (Oro, 1998). The fact that all tagged individuals could be found in both habitats suggests that the use of terrestrial habitat was not due to the casual behaviour of a single individual. This result supports previous studies that describe the use of the rice fields of the Ebro Delta by the Audouin's gull (Ruiz et al., 1996; Mañosa et al., 2004; Longoni, 2010), probably related to the exploitation of the exotic American crayfish (Navarro et al., 2010), which is very abundant in the rice fields of the Ebro Delta (Gutierrez-Yurrita et al., 1999). Although many studies have demonstrated that the Audouin's gull exploits trawler discards (Oro et al., 1997; Arcos, 2001; Cama, 2010), the foraging activity of our satellite-tracked individuals was higher inland than at sea in a period of time that includes the discarding peak of the trawling fleet (from 15 to 16 h; Cama, 2010). This result suggests that terrestrial foraging has become an alternative food source to trawling discards (Navarro et al., 2010), probably prompted by the interference competition for fisheries discards:

namely, intraspecific competition (due to an increasing population density), and interspecific competition with the sympatric and dominant Yellow legged gull *Larus michahellis* (e.g. Arcos et al., 2001).

In conclusion, the present study shows that Audouin's gull foraged in both marine and terrestrial habitats and showed activity during both night and day. These results confirm the high foraging plasticity of Audouin's gull, a species once defined as a specialist nocturnal forager that has become an opportunist on fisheries discards and terrestrial resources. However, due the limited sample size we suggest the necessity of conducting more studies using biologging methodologies (such as PTTs or GPS) to confirm the observed patterns and to gain new insight into the foraging ecology of this endangered seabird.

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Table 1 Summary information of PTTs performance

PTT Id	Sex	Tracking days	First location	Last location	Total locations
58978	♂	2	15/05/2006	16/05/2006	6
58979	♂	1	19/05/2006	19/05/2006	2
58980	♂	10	18/05/2006	27/05/2006	31
58981	♂	2	15/05/2006	16/05/2006	4
58982	♀	7	15/05/2006	21/05/2006	6
58983	♀	0	-	-	-
58984	♀	10	15/05/2006	24/05/2006	32
58985	♀	3	18/05/2006	20/05/2006	8
Total		13	15/05/2006	27/05/2006	89

Fig. 1. (a) Breeding areas of the Mediterranean endemic Audouin's gull *Larus audouinii* and study area: Ebro Delta, NW Mediterranean. (BirdLife International, 2011) (b) Map of the Ebro Delta area indicating the Audouin's gull colony position with an asterisk and 1 km buffer area around la "Punta de la Banya" peninsula, the rice fields and wetlands shaded in dark grey and the location of the main harbors. (c) Foraging locations of 7 satellite-tracked Audouin's gulls during the breeding period of 2006. To better visualize the foraging locations' range the Minimum Convex polygon (short dashed line) is shown beside the 95% (solid line) and 50% (long dashed line) kernel polygons.

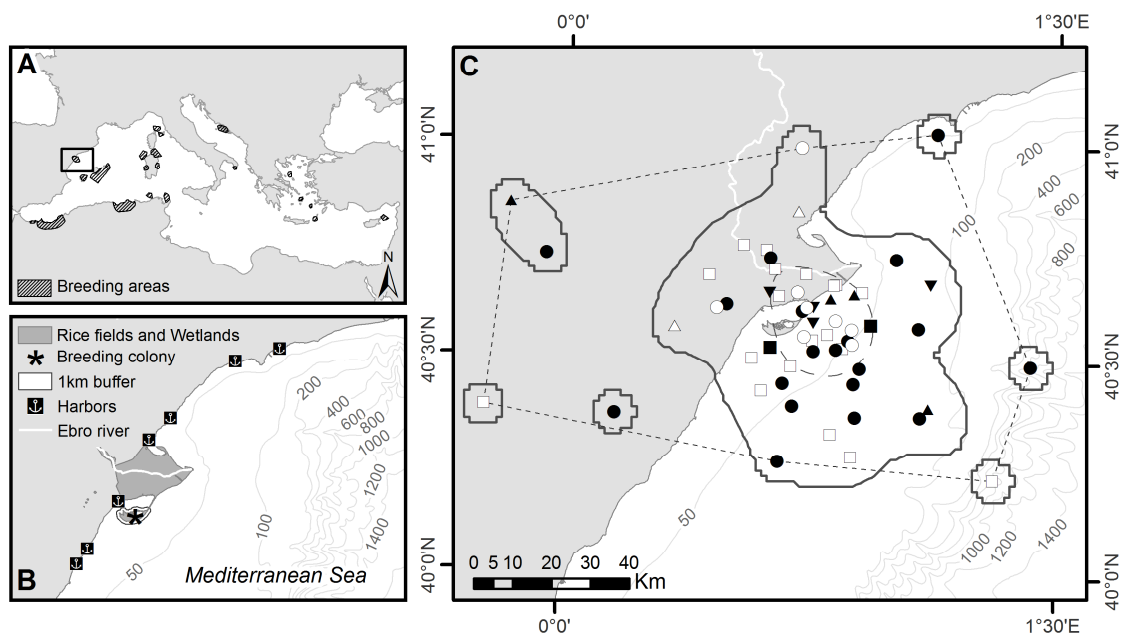


Fig. 2. Example of foraging trajectories for the individual “58980” (see Table 1 for more information)

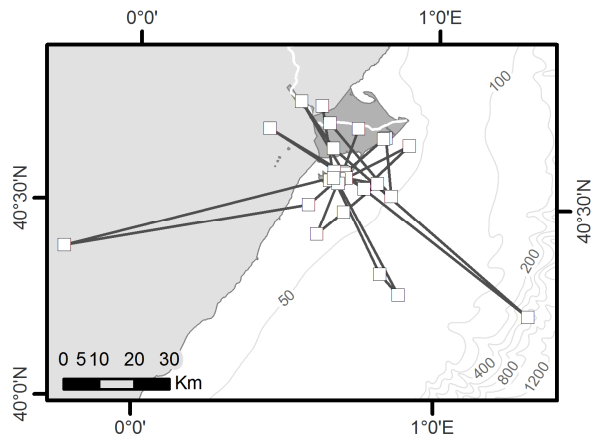


Fig. 3. (a) Activity (foraging in marine or terrestrial habitat; or located in the colony) during a 24h cycle of 7 satellite-tracked Audouin’s gulls during the breeding period in Ebro Delta colony. (b), (c) Mean and 95% confidence interval, of the foraging probability and foraging in marine habitat probability respectively, according to the GLM models. * indicates a significant difference of the time block probability compared to the reference level 7-13 h.

