NO EVIDENCE OF HABITAT EFFECT ON CLUTCH SIZE, EGG QUALITY, AND HATCHING SUCCESS OF THE YELLOW-LEGGED GULL *LARUS MICHAHELLIS* AT A MICRO-SPATIAL SCALE

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ABSTRACT

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In colonial seabirds, the nest substrate that is available and, in particular, the vegetation cover around the nest, are important environmental factors that drive an individual's nesting selection process and, ultimately, reproductive performance. Using data collected during three consecutive years in a Yellow-legged Gull *Larus michahellis* colony from the Bay of Biscay, Spain, we tested whether clutch size, egg volume, and hatching success covaried with the proportion of vegetation cover around nests. We found no effect of vegetation cover on breeding performance. Laying date showed a positive effect on egg volume and a negative effect on hatching success and the number of hatched eggs. Egg volume tended to be smaller in 2020 compared to 2018 and 2019, and hatching success decreased through the sampling period, with the lowest hatching success occurring in 2020. Our findings agree with a previous study in which vegetation had no or unclear effects on breeding performance in Yellow-legged Gulls; however, they contradict other seabird studies that found a positive correlation between the two variables. The role of vegetation on breeding performance could vary not only between gull species, but also geographically, with ecological drivers such as intra- and interspecific interactions and climate playing key roles in observed differences. Finally, the use of egg volume and hatching success as proxies for breeding output could be used for the long-term monitoring of the relationship between breeding performance and factors such as landfill management, fishing, or climate change in the Yellow-legged Gull and other gull species.

Key words: breeding season, habitat selection, nest, seabird, vegetation, Yellow-legged Gull

INTRODUCTION

Reproductive performance is a capital process that strongly affects the demographics of bird populations. Therefore, understanding the factors that influence breeding performance is crucial to assess their impact at the population level (Coulson 2001). Gulls are colonial seabirds, and breeding in dense colonies can potentially result in very high competition for the best nesting sites (Gaston 2004). In general, birds that breed in the center and/or the preferred places within the colony breed with greater success than birds occupying a colony's margins; also at a disadvantage are birds that are exposed to more predators or birds that are less protected against adverse weather conditions (Gaston 2004).

In this context, the availability of nest substrate is an important environmental factor driving the nesting selection process and, ultimately, reproductive performance (Bongiorno 1970, Skorka *et al*. 2005). In a Mediterranean colony of Yellow-legged Gulls *Larus michahellis*, individuals were observed to first occupy zones with a higher percentage of vegetation (relative to zones that were bare; Bosch & Sol 1998), a behaviour also observed in other gulls (Yorio *et al*. 1995, Ellis 2005). Moreover, gull density was higher in these vegetated zones (Bosch *et al*. 1994), although breeding success was similar between habitats (Bosch & Sol 1998). Clutch size differed between these habitat types (increasing in zones with more vegetation), although this difference was attributed to a possible late-season laying (Bosch & Sol 1998). Overall, it appears that dense vegetation in gull colonies improves breeding output by increasing rates of hatching and fledging success (Montevecchi 1978, Parsons 1982, Craik 1999, Garcia-Borboroglu & Yorio 2004, Kim & Monaghan 2005a). This improvement occurs because vegetated areas offer higher protection against bad weather (Kim & Monaghan 2005b) and/or predation (Burger & Shisler 1978). Consequently, nesting density can increase in areas in or close to dense vegetation (Becker & Erdelen 1986). Over time, however, high nest density could produce an impoverishment of vegetation and reduce long-term breeding success (Vidal *et al*. 2000, Ellis *et al*. 2005). It is less clear, however, whether breeding in areas with dense vegetation has any significant relationship to other parameters, such as egg size (Bosch & Sol 1998, but see Becker & Erdelen 1986).

Our aim in this study was to evaluate the effect of nesting habitat, measured at a micro-scale level, on the breeding performance of a Yellow-legged Gull colony. To accomplish this goal, we analysed data collected during three consecutive years from a colony of Yellow-legged Gulls located in the Bay of Biscay, Spain. We hypothesised that a higher proportion of vegetation, compared to bare soil (rock substrate), would be associated with greater breeding output (clutch size, egg volume, hatching success) in the colony under study.

STUDY AREA AND METHODS

The avian model

The Yellow-legged Gull is the most abundant gull of the southwestern Palaearctic region, with a population of *ca*. 150 000–200 000 breeding pairs (Olsen & Larson 2004). In Spain, there are more than 80 000 pairs (Molina 2009), and a significant fraction breeds in the Bay of Biscay along the coast from Galicia (west) to the Basque region (east). The population that breeds along this coast is resident (Munilla, 1997) and has a very restricted flow among colonies; hence, it likely constitutes a meta-population (SD unpubl. data) and is considered to belong to a subspecies, *L. m. lusitanius*, breeding from the Basque coast to southwest Iberia (Olsen & Larson 2004). In the Basque region, where several studies have been carried out, the population has increased 146% since 2000 (Arizaga *et al*. 2009) due to foraging opportunities provided by landfills (Arizaga *et al*. 2010) and discards from the fisheries industry (Foster *et al*. 2017). More recently, the population has been stable or may have declined (Juez *et al*. 2015), principally due to the closure of landfills and increased controls on fisheries discards (Egunez *et al*. 2018, Zorrozua *et al*. 2020a).

Study area and data collection

The data used in this study were obtained from the colony of Ulia (43°20′N, 001°57′W), province of Gipuzkoa, Basque Country, Spain. This colony totals *ca*. 660 pairs, which makes it the main colony in Gipuzkoa and one of the most important Yellow-legged Gull colonies in the Bay of Biscay. The colony is located on coastal cliffs, with nests spread across a mixture of patches of bare soil (sandstone rock) and vegetation. The vegetation within the colony is mostly composed of herbaceous species (Eagle Fern *Pteridium aquilinum*, Cornish Heath *Erica vagans*, Coastal Spleenwort *Asplenium maritimum*) mixed with small stands of American Pokeweed *Phytolacca americana* and Saltbush *Baccharis halimiolia*, the latter two of which are invasive American plants. Plants within the colony usually achieve a height < 1 m.

This study extended over three breeding years, 2018–2020. The breeding season lasted from mid-April (when eggs are laid) to the end of June (when most chicks are about to fledge; Mínguez 1988, Galarza 2008, Arizaga *et al*. 2012). The colony was surveyed every two days from 20 April to 25 June. Visits were cancelled/postponed in cases of adverse weather (e.g., rain or very strong winds). Once in the colony, we looked for nests during the entire laying period and marked each nest with a stake displaying a small, numbered flag (40 cm high). Nests were selected randomly within zones that were relatively easy to survey (nests in very steep, inaccessible cliffs could not be monitored). Eggs were marked using a felt-tipped pen according to their laying order—both with letters (A, B, and C) and their laying day (assuming a maximum laying interval of 48 h). If, in each visit, a nest had two or more new eggs, eggs were marked as AB, BC, or ABC because we were unable to determine laying order. At the end of the incubating period, we determined—for each egg—whether it hatched, failed (a non-broken, non-hatched egg), or other (that is, the egg was broken or disappeared due to predation or accident).

Once identified, the following variables were measured: (1) laying date (for the first egg); (2) laying sequence for each egg (with a letter A, B, C); (3) clutch size; (4) egg size (length [L], width [W], measured with a digital caliper with ±0.01 mm accuracy); and (5) hatching success. Thereafter, egg volume was calculated as: $0.000476 \times L \times W^2$ (Bolton *et al*. 1992).

Apart from breeding parameters, the type of substratum around each nest was also recorded. Specifically, we assessed the proportion of the total area within a 1-m radius around each nest that was covered by bare soil (rock) or vegetation.

Statistical modelling

First, we removed five nests ($n = 1$ in 2018, $n = 2$ in 2019, $n = 2$ in 2020) from the data set that had a clutch size of one egg, which were otherwise very rare within the colony.

To assess whether the habitat type at a micro-scale level affected the breeding parameters listed above, we built Generalized Linear Models (GLM), with year as a factor and the laying date and proportion of vegetation cover as covariates. The type of link-function and the errors' distribution used in each GLM varied in relation to the nature of each object variable. Thus, we used a linear-link function with normal errors for the following dependent variables: laying date, hatching date, and mean and maximum egg volume. By contrast, we used a logit-link function with negative binomial errors' distribution for hatching success (0 = no hatching, 1 = one or more eggs hatched). The analyses were carried out with the software R (R Core Team 2014) and the package "lmerTest" (Kuznetsova *et al*. 2017); post-hoc tests (Tukey test and Chi square test) were applied.

RESULTS

We sampled 267 nests (see Table 1), containing 752 eggs in total, all of which were measured. Mean clutch size (± standard deviation, SD) was 2.81 ± 0.38 eggs/nest, and the mean and maximum egg volume per nest was, respectively, 72.1 ± 5.48 cm^3 and 75.6 ± 6.25 cm^3 (Table 1). Overall, 233 (87.3%) nests had at least one hatched egg (Table 1), and of the 752 eggs laid, 486 (64.6%) hatched successfully; 171 eggs (22.6%) did not hatch, and 95 eggs (12.6) were broken or disappeared (Table 1). The mean percentage of vegetation cover around nests was 71.10% ± 34.18% (Table 1).

Clutch size, egg volume, and hatching did not vary in relation to vegetation cover (Table 2). A later laying date showed a positive effect on egg volume but a negative effect on hatching success and hatched eggs (Table 2). Finally, egg volume tended to be smaller in 2020 compared to 2018 and 2019, and hatching success decreased through the sampling period, with the lowest values occurring in 2020 (Table 2).

DISCUSSION

This study analysed, for the first time, the influence of vegetation cover on the breeding performance of a Yellow-legged Gull population of the *L. m. lusitanius* subspecies. It adds to the findings of other studies on the effect of vegetation cover on gulls' breeding performance (see Ellis 2005), including in the Yellow-legged Gull (Bosch & Sol 1998).

We found no evidence of an effect of vegetation cover on any of the analysed breeding parameters (clutch size, egg volume, hatching).

TABLE 1
Breeding parameters of a Yellow-legged Gull *Larus michahellis* colony in the Bay of Biscay, Spain, 2018–2020[a]

	2018	2019	2020	Total/mean values
Sample size (nests)	172	50	50	272
EGGS				
Sample size (eggs)	494	134	129	757
Clutch size (eggs)	2.88 ± 0.32	2.75 ± 0.43	2.64 ± 0.48	2.81 ± 0.38
Mean volume (cm^3)	73.05 ± 5.13	71.037 ± 6.56	70.32 ± 4.95	72.19 ± 5.48
Max. volume (cm^3)	76.21 ± 5.82	75.39 ± 7.92	73.60 ± 5.57	75.60 ± 6.25
HATCHING				
Hatching success: % (count)	89.5% (153)	93.8% (45)	64.6% (31)	87.3% (233)
Hatched eggs: % (count)	66.5% (326)	74.4% (99)	47.6% (64)	64.6% (486)
Hatched eggs	326	99	64	486
Hatched egg per nest	1.89	1.96	1.26	1.78
Non-hatched eggs: % (count)	20.0% (99)	25.6% (35)	32.6% (39)	22.7% (171)
Broken/disappeared eggs: % (count)	13.5% (69)	0.0% (0)	19.8% (26)	12.6% (95)
VEGETATION				
Vegetation cover (%)	70.09 ± 35.67	73.12 ± 33.65	72.70 ± 29.444	71.10 ± 34.18

[a] Mean values have been provided ± standard deviation; units shown in parentheses

This result agrees with a previous study in which vegetation had no or unclear effects on breeding performance in another Yellow-legged Gull colony (Bosch & Sol 1998), but it is in contrast to studies in which dense vegetation was found to improve hatching success (Bosh & Sol 1998, Rodway & Regehr 1999). The role of vegetation on breeding performance could vary not only between species, but also geographically, with ecological drivers such as intra- and interspecific interactions and local climate playing key roles in observed differences. In theory, the amount of vegetation cover could be more critical in denser colonies, in colonies with higher predation pressure, in colonies that are more susceptible to disturbance, or in colonies that are subject to harsher climatic conditions (such as high temperatures and insolation; With & Webb 1993, Miyazaki 1996, Kim & Monaghan 2005b). None of these circumstances are applicable to our survey colony.

The effect of vegetation through phases of the breeding period (i.e., during the chicks rearing period) is unclear. Presumably, chicks surrounded by more vegetation would benefit from greater protection against bad weather and predation (Saliva & Burger 1989, Kim & Monaghan 2005b), as well as attacks from conspecifics (Burger 1977, Krause & Ruxton 2002, Kim & Monaghan 2005b). Overall, our breeding colony is characterized by vegetation cover that grows in parallel with the breeding

TABLE 2
Beta-parameter estimates obtained from a set of models used to determine the effect of vegetation cover and other parameters on breeding performance of a Yellow-legged Gull *Larus michahellis* population from the Bay of Biscay, Spain[a,b]

	VC	DT	YR: 2019	YR: 2020
Clutch size $R^2 = 0.06$	+0.00 ± 0.00 (0.893)	−0.00 ± 0.01 (0.837)	−0.06 ± 0.12 (0.607)	−0.09 ± 0.10 (0.374)
Mean volume $R^2 = 0.07$	+0.01 ± 0.01 (0.483)	+0.21 ± 0.08 **(0.006)**	−0.26 ± 1.08 (0.813)	−2.04 ± 0.91 **(0.025)**
Max. volume $R^2 = 0.06$	+0.01 ± 0.01 (0.667)	+0.26 ± 0.09 **(0.004)**	+1.28 ± 1.25 (0.304)	−1.80 ± 1.04 (0.086)
Hatching success $R^2 = 0.20$	+0.00 ± 0.00 (0.723)	−0.23 ± 0.90 **(< 0.001)**	−1.80 ± 0.90 **(0.045)**	−2.71 ± 0.54 **(< 0.001)**
Hatched eggs	−0.00 ± 0.00 (0.452)	−0.04 ± 0.01 **(0.001)**	−0.20 ± 0.14 (0.149)	−0.47 ± 0.14 **(< 0.001)**

[a] Independent variables: VC, vegetation cover; DT, laying date; YR, year.
[b] Beta parameter estimates are values ± standard error, P values are in parentheses, and significant values ($P < 0.05$) are in bold font.

season—it is relatively small during the first weeks of the breeding period (i.e., egg laying, incubation) and grows larger as the breeding period progresses. In this scenario, it is possible that in other, similar colonies, vegetation may have a null or marginal (undetectable) effect over the breeding period.

The mean values of the analysed breeding parameters show a clutch size similar in value to other large gulls, in which size varied from 2.5 to 2.9 (Monaghan *et al*. 1991, Bosh & Sol 1998, Baaloudj *et al*. 2014, Hammouda *et al*. 2014). Mean egg volume for each nest was also similar in this study to some other gull colonies (Monaghan et al. 1991), although it was lower than in others (Isenmann 1976, Baaloudj *et al*. 2014, Hammouda *et al*. 2014). Hatching success in this colony was greater than in several other colonies (Isenmann 1976, Bosh & Sol 1998, Moulaï *et al*. 2006, Baaloudj *et al*. 2014), yet it was similar to hatching success in northern European populations (Oro *et al*. 1995; Bosch *et al*. 2000, Duhem *et al*. 2002).

In general, seabird colonies show a decrease in hatching success and overall breeding performance with a later laying date (Davis 1975, Bosman 2014, Galarza & Arizaga, 2014), an outcome that was also observed in our study. However, unexpectedly, we observed that a later laying date had a positive effect on egg volume. Egg volume is correlated with eventual greater chick mass and body condition, increasing chick survival (Bolton 1991, Kubelka *et al*. 2020). For late lay nests or replacement eggs, egg-size is typically lower at laying, producing a small-volume egg (Birkhead & Nettleship 1982).

We detected significant yearly variation in egg volume and hatching. More specifically, all parameters tended to decrease during the three study years and were lowest in 2020. From a meteorological standpoint, the spring of 2020 was not colder or more rainy than previous springs (Table 3). Therefore, weather may not be a direct factor explaining these inter-annual variations, but it could affect changes in diet and food access. Thus, our colony, and the entire Yellow-legged Gull population from the southeastern Bay of Biscay, may be experiencing a change in its trophic ecology because of the effects of landfill closures and changes in the management of fish discards (Arizaga *et al*. 2018, Zorrozua *et al*. 2020a, 2020b). Access to food from open-air landfills within the study region has been decreasing; the only site open during 2018–2020 was at Zaluaga (43°22′N, 001°34′W), 22 km away in France. The processing and waste treatment on this landfill changed in October 2019, decreasing food availability for opportunistic species.

TABLE 3
Meteorological parameters obtained from the Euskalmet Santa Clara station, Spain, 2018–2020

	2018	2019	2020
April			
Precipitation (L/m^3)	225.5	115.7	106.7
Mean temperature (°C)	14.4	12.1	14.5
Minimum mean daily temperature (°C)	11.1	10.5	12.0
May			
Precipitation (L/m^3)	114.3	164	104.2
Mean temperature	14.5	15.7	16.53
Minimum mean daily temperature (°C)	12.0	13.5	13.8
June			
Precipitation (L/m^3)	94.2	67.1	108.7
Mean temperature (°C)	18.3	17.7	16.8
Minimum mean daily temperature (°C)	15.83	14.4	14.48

It is noteworthy that the number of chicks ringed in the Ulia colony in 2019 and 2020 (n = 43 and 76, respectively; JA unpubl. data) was remarkably lower than in 2018 (n = 170), even though we invested a similar ringing effort. These data indicate that egg volume and/or hatching success may be used as a proxy for the colony's breeding output.

Despite finding no effect of vegetation cover on gulls' breeding performance, we uncovered interesting annual variation in parameters such as egg volume, hatching success, and the number of hatched eggs, which are worth studying in the future. Monitoring long-term changes in these parameters could provide a pool of variables that could be used to evaluate the relationship between breeding performance and factors such as landfill management, fishing, or climate change (Belant *et al*. 1993, Oro *et al*. 1995, Real *et al*. 2017). Other breeding parameters, such as productivity, are much more difficult to measure because gulls can occupy colonies having an intricate topography, making measurement problematic.

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