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Short Communication

No detrimental effects of wing-harnessed GPS devices on the breeding performance of Yellow-legged Gulls (*Larus michahellis*): A multi-colony evaluation

CHARLY SOUC,*[1] CAROLE LERAY,[2]
THOMAS BLANCHON,[2] THOMAS DAGONET,[2]
MARION VITTECOQ,[2] RAÜL RAMOS[3,4] &
KAREN D. MCCOY[1]
[1] *MIVEGEC, University of Montpellier, CNRS, IRD, Centre IRD, Montpellier, France*
[2] *Tour du Valat, Research Institute for the Conservation of Mediterranean Wetlands, Arles, France*
[3] *Departament de Biologia Evolutiva, Ecologia i Ciències Ambientals, Facultat de Biologia, Universitat de Barcelona (UB), Barcelona, Spain*
[4] *Institut de Recerca de la Biodiversitat (IRBio), Universitat de Barcelona (UB), Barcelona, Spain*

A recent study revealed that wing-harnessed tracking devices negatively affected reproductive success of Great Black-backed Gulls *Larus marinus*. To evaluate the generality of this effect in large gulls, we investigated the reproductive performance associated with the same type of GPS-mounted system in four Mediterranean breeding colonies of the Yellow-legged Gull *Larus michahellis* in 2022. We found no significant difference in reproductive parameters among adults handled with a mounted device, adults handled with no device, and controls, and no interaction with colony of origin. The impact of the GPS harness system on short-term reproduction is therefore not generalizable among larid species, and should be tested and reported whenever a new tracking programme is employed.

Keywords: animal welfare, bio-logging, reproductive success, seabird tracking, thoracic harness.

*Corresponding author.
Email: charly.souc@ird.fr

Animal-borne tags, such as miniaturized GPS devices that upload data through diverse telecommunication networks, are now widely used in ecological studies, contributing to notable advances in our understanding of animal biology and ecology, with numerous practical implications. Indeed, the results of these tracking studies have proven useful for developing conservation strategies (Hebblewhite & Haydon 2010, Wilson *et al.* 2015), understanding epidemiological patterns (Navarro *et al.* 2019, McDuie *et al.* 2022), and even in detecting illegal fishing (Weimerskirch *et al.* 2020) and unauthorized rubbish dumps (Navarro *et al.* 2016). However, the use of these tags and their attachment method, whether short-term or long-term, may cause detrimental and undesired impacts on the movement capabilities, reproduction or survival of the tracked wildlife. For instance, the extra weight of GPS tags or the physical limitations of the attachment method have been known to cause physical injuries, physiological impacts, behavioural changes, impaired reproductive success and reduced survival rates in several bird species (Barron *et al.* 2010, Passos *et al.* 2010, Bodey *et al.* 2018, Brlík *et al.* 2020, Clewley *et al.* 2022). The magnitude of these effects may vary among species (Weiser *et al.* 2016) and potentially among locations. Moreover, if tracking devices have a significant impact on the behaviour of individuals, the resulting data may be highly biased and therefore unusable for inferring the normal movements of the studied individuals (Cleasby *et al.* 2021). There is a consensus among researchers that a maximum limit of 5% of the animal's body mass should not be exceeded for the tracking device weight in order to minimize any of the aforementioned impacts (Kenward 2000, Casper 2009). However, 5% may be more or less important depending on the organism. In the case of seabirds, a maximum threshold of 3% of the bird's body mass is frequently used to avoid detrimental impacts (Phillips *et al.* 2003), but this does not preclude a direct evaluation of potential tagging effects on individual behaviour and fitness (Lameris & Kleyheeg 2017).

The impact of mounted tags has been investigated in several gull species (Laridae). Studies on Black-legged Kittiwakes *Rissa tridactyla* demonstrated physiological impacts and behavioural changes caused by tracking devices, although no significant influence on reproductive success was found (Heggøy *et al.* 2015, Chivers *et al.* 2016). Research on Lesser Black-backed Gulls *Larus fuscus* revealed neither survival nor reproductive effects of wing-harnessed tracking (Thaxter *et al.* 2014, 2016, Kavelaars *et al.* 2018). Similarly, O'Hanlon *et al.* (2022) found that resighting rates were unaffected in Herring Gulls *Larus argentatus* that carried wing-harnessed tracking devices. However, Amlaner *et al.* (1978) documented lower reproductive success for individuals equipped with dummy tags. Moreover, a recent study on the Isle of May (Scotland) focusing on the largest gull species, the Great

Black-backed Gull *Larus marinus*, demonstrated a negative effect of wing-harnessed tracking devices on breeding success and, specifically, on hatching success and the number of hatched eggs (Langlois *et al.* 2023). Most of these past studies are based on results from a single breeding colony, and often have relatively low sample sizes. The contrasting effects of wing-harnessed tracking devices on different species and studies highlight the need for complementary tests of these effects using well-balanced designs and diverse colonies/populations of the same species.

Here, we examine the potential impact of deploying permanent wing-harnessed tracking devices in another large gull, the Yellow-legged Gull *Larus michahellis*, using data from 120 monitored nests across four breeding colonies. Specifically, we test (1) if reproductive success decreases due to the presence of a mounted device on at least one of the adults of a breeding pair and (2) if these potential effects vary among colonies with distinct environmental contexts. To disentangle the effect of handling from device deployment, we compared the reproductive success of three treatment groups: handled with device (tagged), handled only and unhandled (control). If wing-harnessed tracking devices impact gull breeding success, then we expected significantly lower reproductive parameters in nests where an adult carried a device compared with the other two groups. We also expected to see the same general pattern among groups in different colonies. If the effects of the tracking devices vary among colonies, this suggests that variation in resource utilization or reproductive conditions may alter the ability of individuals to compensate for the added effect of the device.

METHODS

Study area, design and sampling

Breeding adult captures were conducted from late March to early April 2022 at four colonies located along the Gulf of Lion in the western Mediterranean region (Fig. 1) as part of a multi-year research programme investigating the interplay between gull movements and their health. These breeding colonies vary in size and habitat: (1) Frioul with 5878 breeding pairs in 2021 includes several aggregated rocky islands in close proximity to the highly urbanized city of Marseille, (2) Carteau with 325 breeding pairs in 2021 is a small flat islet within the Camargue marshlands close to an industrial zone, (3) Planasse with 1770 breeding pairs in 2021 is a protected island in the Bages-Sigean lagoon 7 km from the open sea and (4) Medes with 4339 breeding pairs in 2019 (Bosch pers. comm.) are a group of small rocky islands offshore from a small resort town in Spain bordered by agricultural lands.

Monitoring of the four breeding colonies began in late March 2022 and continued until mid-June when chicks had started to fledge. At each colony, 30 nests were selected randomly and monitored throughout the breeding season (n = 120 nests). Captures were attempted in almost all nests during mid-incubation using tent spring traps (1.0 m × 1.0 m or 0.8 m × 0.8 m). We captured 78 breeding adults from 75 nests, and equipped 32 adults with tracking devices. These individuals were held for a longer duration compared with the other handled, but untagged, individuals, but this duration was not recorded. We deployed four models of Ornitela© GPS transmitters (Ornitela UAB, Lithuania: OT-20-3GC, OT-25-3GC, OT-E25-2GC, OT-20-4GC) with a permanent attachment system for long-term monitoring. The OT-20-3GC and OT-20-4GC models weighed approximately 22.7 g, including the attachment system, and had the same dimensions (31 × 60 × 15 mm). Conversely, the OT-E25-2GC and OT-25-3GC models were slightly heavier (27.9 g, including the attachment system), and larger (31 × 60 × 26 mm for the OT-E25-2GC and 31 × 60 × 20 mm for the OT-25-3GC). Only model OT-20-3GC was deployed at Carteau, Frioul and Planasse, whereas all four were used on Medes. The devices were attached to the bird's back using the standard wing-loop configuration (Thaxter *et al.* 2014), where the knot connecting the four Teflon cords (6.35 mm) was positioned above the sternum, at the level of the tracheal pit (Thaxter *et al.* 2014). On average, the weight of the tracking device plus harness did not represent more than 2.3% of the bird's body mass (range 1.71–3.49%, see Supporting Online Material Table S1). All handled birds were marked with PVC and metal rings, weighed and measured for standard biometric parameters. We also took faecal swabs, a feather sample and a blood sample for a separate study. Nests were categorized as: (1) tagged nests where at least one adult was captured and equipped with a tracking device (n = 32), (2) handled nests where at least one adult was captured at the site, but no device was deployed (n = 43), and (3) control nests where no adults were handled (n = 45). Sample sizes of each nest category varied slightly among colonies: Carteau with 7 tagged, 13 handled and 10 control nests; Frioul with 8 tagged, 8 handled and 14 control nests; Planasse with 5 tagged, 14 handled and 14 control nests; and Medes with 12 tagged, 8 handled and 10 control nests. For three nests, the two breeding adults were captured together and handled: two nests were considered handled because no bird was tagged, and one nest was considered tagged as a device was deployed on one of the two adults.

Every nest was monitored once per week through direct visits to the colonies from incubation until close to the end of chick-rearing. Each visit was limited to a maximum duration of 3 h, during which we searched for the chicks around each nest with the same approximate effort. At hatching, chicks were ringed with small,

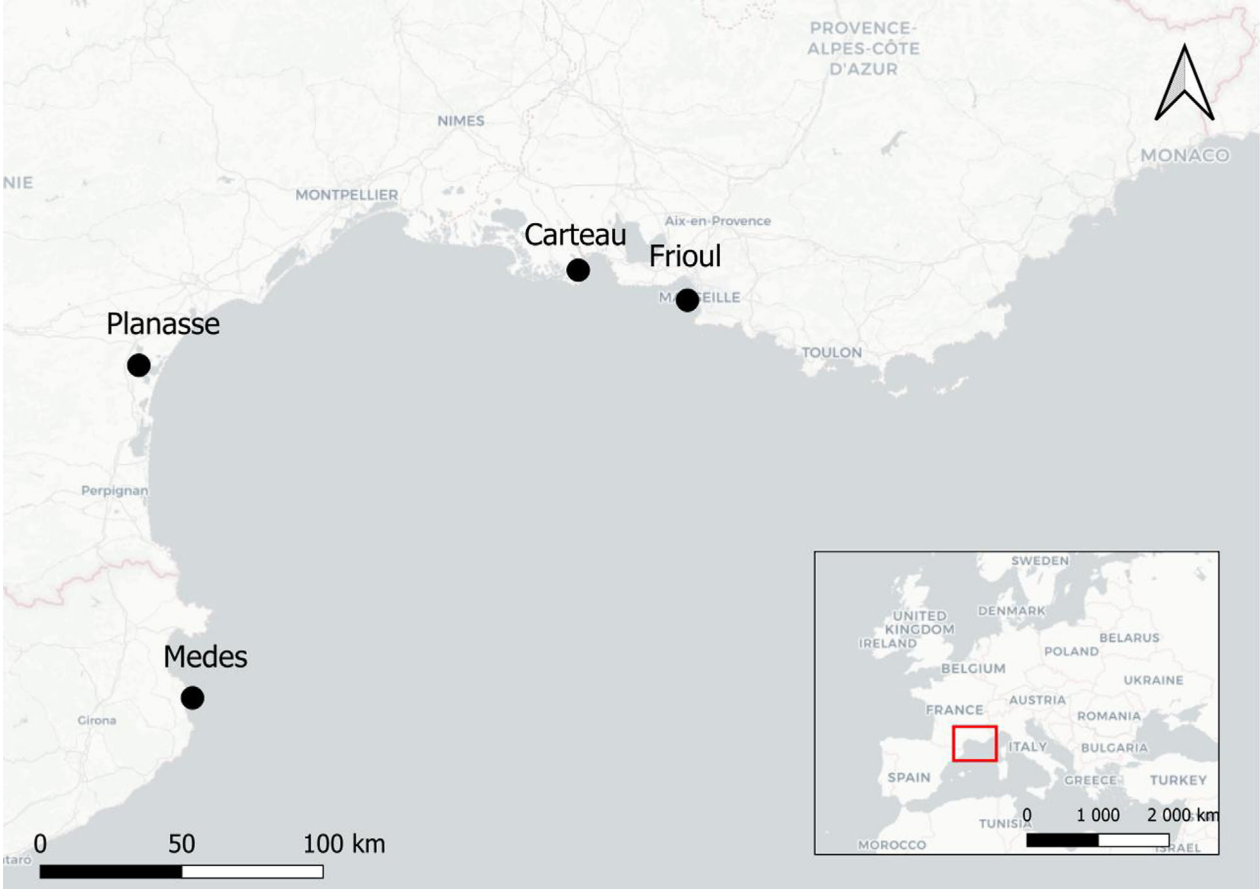

Figure 1. Location of the four monitored Yellow-legged Gull colonies along the northwestern coast of the Mediterranean Sea.

temporary, coloured rings. Once they reached a suitable size, these rings were replaced with metal and PVC rings engraved with unique alphanumeric codes. As per Langlois *et al.* (2023), we considered four breeding parameters: (1) hatching success (binary, whether at least one egg hatched or not), (2) number of hatched eggs per nest, (3) fledging success (binary, whether at least one chick per hatched nest fledged or not), and (4) number of chicks that fledged per nest. To enable a direct comparison with the results of Langlois *et al.* (2023), we did not take into account clutch size in these estimates.

Statistical analyses

All analyses were carried out in R version 4.3.1 (R Core Team 2023, Vienna, Austria).

To examine the impact of tracking devices on reproductive performance, the four breeding parameters were modelled as response variables using Generalized Linear Models (GLMs), with colony and treatment group as explanatory variables. GLMs for binary hatching and fledging success were fit with binomial distributions, and those for count data (number of hatched eggs and number of fledged chicks) were fitted with Poisson distributions. Overdispersion for the Poisson GLMs was checked using the *AER* package (Kleiber & Zeileis 2008). Model selection was based on the corrected Akaike's Information Criterion (AICc). When multiple models displayed a ΔAICc of less than 2, we performed an analysis of deviance (ANODEV) to evaluate their relative performance. This analysis allows us to determine if differences in model fit are statistically significant, aiding in the selection of the most appropriate model for our data. Then subsequent *post-hoc* Tukey tests were conducted using the *multcomp* package (Hothorn *et al.* 2008) on the selected models to examine the source of differences. All nests were included in this analysis, including those for which both adults were captured (n = 120 nests).

In order to determine the possible additional impact of body mass on reproductive success, we remodelled reproductive success using only tagged and handled individuals. As above, the four breeding parameters were modelled as response variables in GLMs, but this time, we included body mass, as well as treatment group and colony as explanatory variables. When the effects of treatment group and/or colony were not retained during the first model selection procedure (i.e. without mass), they were deemed to have no effect on the response variable and were excluded from the model set. The three nests with two handled adults were excluded from this analysis (n = 72 nests).

Finally, to examine the impact of relative device mass on reproductive performance, we conducted an ANODEV using the tagged nests only (n = 32 nests), comparing null models with models that incorporated the device mass relative to bird mass as an explanatory variable. For each of the four response variables, we expected the model that included relative tag mass to perform better than the null model, if the weight of the tag had an impact on reproduction.

RESULTS

The selected model for hatching success incorporated an additive effect of treatment group and colony (Table 1). The *post-hoc* test highlighted that this effect seemed to be the result of a difference between the control group and the other two groups, with a P value of 0.187 between the control and tagged groups, and a P value of 0.068 between the control and handled groups (Table S2a). Birds in the control group appeared to have lower hatching success compared with the other two groups. Indeed, mean hatching success was slightly lower for control nests (Fig. 2a and Table 2). Although the *post-hoc* tests on colony showed no significant differences, it should be noted that 54% of hatching failures were from the Planasse colony (Table S1 and Fig. S1).

The number of hatched eggs was not significantly influenced by any considered factor (Table 1) and the mean number of hatched eggs was similar among treatment groups (Fig. 2b and Table 2).

Fledging success was solely influenced by colony and the same pattern emerged for the number of fledged chicks (Table 1); means for treatment group were relatively close and confidence intervals were wide and overlapping (Fig. 2c, d and Table 2). *Post-hoc* tests comparing differences between colonies revealed a significant distinction between the Medes and Carteau colonies concerning fledging, with both lower fledging success (P = 0.036; Table S2b) and number of fledged chicks (P = 0.037: Table S2c) at Medes.

Table 1. Model selection for the four measured reproductive parameters based on the Akaike Information Criterion corrected for small sample sizes (AICc). ΔAICc indicates the difference in AICc values between the model in question and the best-performing model. Models with ΔAICc of more than 2.0 are considered to be significantly different from the best model. Residual degrees of freedom denotes the remaining degrees of freedom after model fitting and Residual deviance quantifies the unexplained variability in the model. Rows highlighted in bold correspond to the best performing models. The Null model serves as a baseline model with no explanatory variables.

Response variable	Model terms	AICc	ΔAICc	Residual degrees of freedom	Residual deviance
Hatching success	**Colony + Treatment group**	**69.3**	**0.0**	**114**	**56.6**
	Colony	72.6	3.3	116	64.2
	Treatment group	73.4	4.1	117	67.2
	Null	75.6	6.3	119	73.5
	Colony*Treatment group	79.7	10.4	108	52.8
Number of hatched eggs	**Null**	**364.1**	**0.0**	**119**	**74.0**
	Colony	367.5	3.3	116	71.0
	Treatment group	367.7	3.5	117	73.3
	Colony+Treatment group	371.6	7.4	114	70.7
	Colony*Treatment group	379.3	15.1	108	64.3
Fledging success	**Colony**	**133.1**	**0.0**	**105**	**124.7**
	Null	135.7	2.6	108	133.7
	Colony+Treatment group	136.1	3.0	103	123.3
	Treatment group	138.9	5.8	106	132.7
	Colony*Treatment group	142.9	9.8	97	115.6
Number of fledged chicks	**Colony**	**305.7**	**0.0**	**116**	**119.8**
	Null	307.9	2.2	119	128.3
	Colony+Treatment group	309.7	3.9	114	119.3
	Treatment group	311.4	5.7	117	127.6
	Colony*Treatment group	318.0	12.2	108	113.5

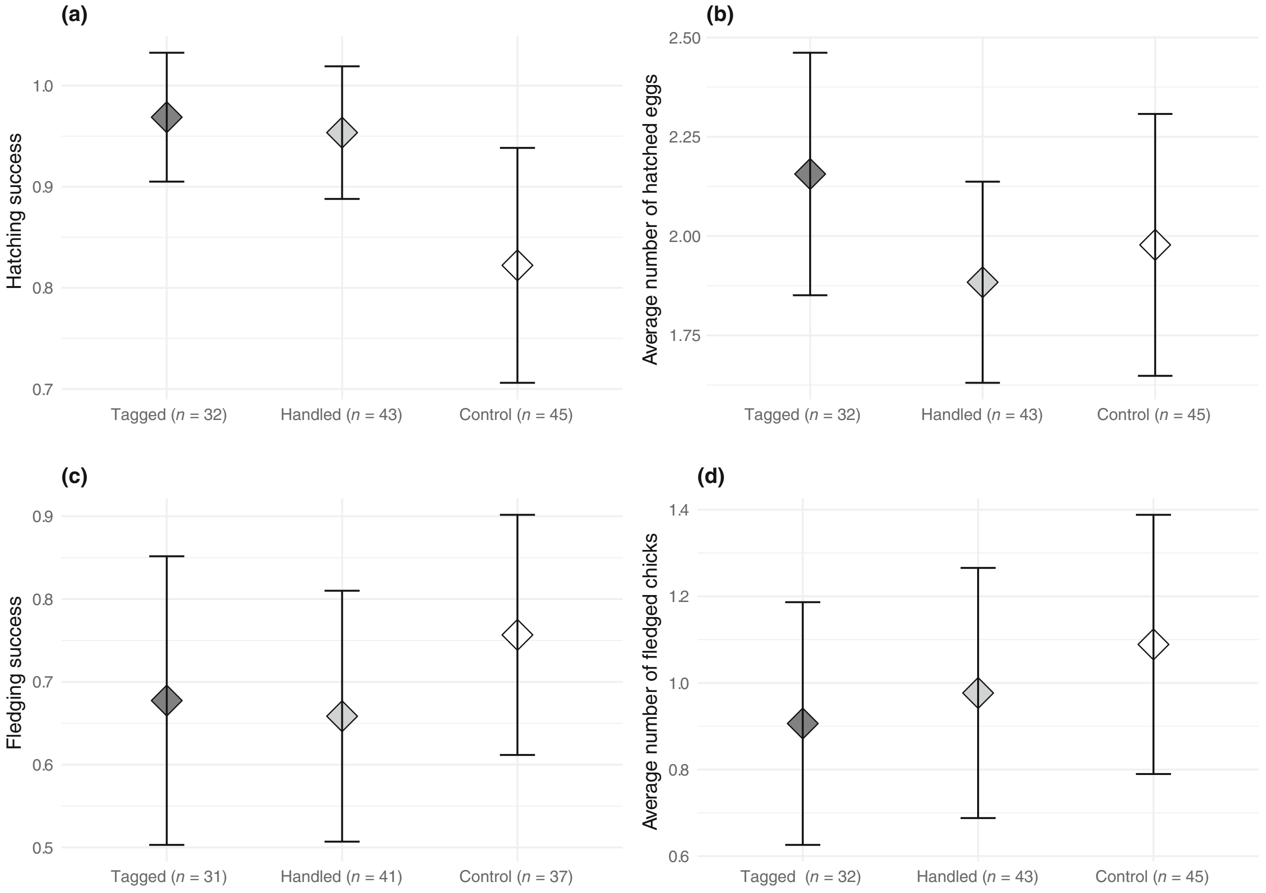

Figure 2. Mean reproductive parameters across colonies according to treatment group (tagged in dark grey, handled in grey and control in white), along with their 95% confidence intervals. (a) Hatching success; (b) number of hatched eggs; (c) fledging success; (d) number of fledged chicks. Fledging success is only measured for nests that hatched at least one chick. (a) and (b) are binary; a nest was considered successful if at least one egg hatched or at least one chick fledged.

Effect of body mass

It was difficult to conclude on the effect of body mass on hatching success; the null model exhibited the lowest AICc, but two other models showed similar performance (see Table S3). One model considered only the effect of mass, and the other an interaction between mass and treatment group. The ANODEV did not yield any significant difference among these three models. This could be due to an imbalance in the distribution of binary variables, with only three nests failing to hatch out of 72 observations. No influence of mass was found on the number of hatched eggs, as the null model showed a similar fit to the other models (Table S4). Regarding fledging success, only body mass was retained in the model selection process. The coefficient associated with the effect of mass suggested that the bird's mass had a positive influence on fledging success (coefficient = 0.01, ± 0.002 se, $P = 0.010$). For the number of fledged chicks, the null model was nearly equivalent in terms of AICc compared with the most complex model (ΔAICc = 0.9), and the ANODEV did not reveal a significant difference between the null model and the model considering only the effect of mass, although a tendency is possible ($P = 0.078$). Therefore, there is a potential weak effect of mass on fledging success, but no effect of treatment group (handled or tagged) or an interaction between treatment group and mass on the number of fledgings. In contrast to the initial model, colony did not emerge as a significant predictor of the response variable in this analysis.

Effect of relative tag mass

None of the measures of reproductive success appeared to be influenced by relative device mass to bird mass. Indeed, during the ANODEV, none of the models incorporating this parameter as an explanatory variable

Table 2. Mean reproductive parameters according to colony and treatment group along with their 95% confidence intervals. Fledging success is only measured for nests that hatched at least one chick. A nest was considered successful if at least one egg hatched or at least one chick fledged.

Colony	Frioul	Carteau	Planasse	Medes
Hatching success	1.00 (1.00–1.00)	0.90 (0.79–1.01)	0.80 (0.65–0.95)	0.93 (0.84–1.03)
Number of hatched eggs	2.20 (1.92–2.48)	2.00 (1.65–2.35)	1.63 (1.22–2.04)	2.13 (1.81–2.45)
Fledging success	0.70 (0.53–0.87)	0.89 (0.76–1.02)	0.67 (0.46–0.87)	0.54 (0.34–0.73)
Number of fledged chicks	1.13 (0.80–1.47)	1.33 (1.00–1.66)	0.90 (0.52–1.28)	0.63 (0.37–0.90)
Treatment group	**Tagged**	**Handled**	**Control**	**Total**
Hatching success	0.97 (0.91–1.03)	0.95 (0.89–1.02)	0.82 (0.71–0.94)	0.91 (0.86–0.96)
Number of eggs hatched	2.16 (1.85–2.46)	1.88 (1.63–2.14)	1.98 (1.65–2.31)	1.99 (1.82–2.16)
Fledging success	0.68 (0.50–0.85)	0.66 (0.51–0.81)	0.76 (0.61–0.90)	0.70 (0.61–0.78)
Number of fledged chicks	0.91 (0.63–1.19)	0.98 (0.69–1.27)	1.09 (0.79–1.39)	1.00 (0.83–1.17)

exhibited significant differences compared with the null model (hatching success: $P = 0.314$; number of hatched eggs: $P = 0.736$; fledging success: $P = 0.242$; and number of fledged chicks: $P = 0.184$; see Table S5).

DISCUSSION

Overall, we did not detect a negative impact of wing-harnessed tracking devices or bird capture on breeding success. There was a slight effect of treatment group on hatching success, but in this case, control nests actually showed lower hatching success. Our results contrast with those in Great Black-backed Gulls (Langlois *et al.* 2023), despite a larger sample size, with nearly three times as many birds equipped with tracking devices and twice as many individuals falling under the handled/tagged categories. The harness attachment method was consistent across the two studies, as was the overall weight of the device (relative tag mass was even slightly higher in our study). These different results could be species-specific, as a previous study suggested sensitivity to device tags in Great Black-backed Gulls (Maynard *et al.* 2022). Yellow-legged and Great Black-backed Gulls are closely related species, with similar breeding ecologies but typically differ in foraging ecologies. Great Black-backed Gulls often hunt actively for food (Buckley 1990, Farmer & Leonard 2011), whereas Yellow-legged Gulls are much more opportunistic, frequently feeding on waste or discards (Ramos *et al.* 2009, Ceia *et al.* 2014). Such differences could explain the sensitivity of Great Black-backed Gulls to the presence of tags, which could hinder flight agility during predation. The discrepancy between studies could also be due to colony-specific differences. Indeed, both Amlaner *et al.* (1978) and Langlois *et al.* (2023) only considered a single colony in their study and suggested the possibility that their results were the result of local effects. In our study, certain reproductive parameters were indeed observed to be influenced by colony location. For instance, the average number of fledglings per nest was nearly half as much at Medes compared with Carteau (Table 2). These disparities are likely to be the result of inherent differences in colony quality (i.e. habitat, resource quality and availability, predation rate). Nevertheless, within our study area, no discernible interaction between colony and treatment group on reproductive success was found, suggesting that our results are common to all colonies. It is possible that this effect was missed because of small sample sizes, but *post-hoc* power analyses suggest that, if present, this effect is weak at best (see Appendix S1). Indeed, models that included colony*nest interactions were never ranked among the top models during model selection (see Table 1). The four colonies included in this study were all large and relatively successful in terms of breeding (>0.5 fledging success). It is possible that alternative outcomes might have arisen if colonies of significantly lower quality had been included in the analyses.

As mentioned above, the only impact of treatment group on breeding success was on hatching success. However, in this case, it was the control birds that displayed reduced success compared with handled/tagged birds. In our dataset, hatching success constitutes a strongly imbalanced binary parameter, with only 11 of 120 nests failing to hatch at least one chick (see Table S1). It may be that our result is due to the state of the nest during the capture period. Indeed, failed nests may have included nests that had already been deserted by mid-incubation or were attended by less committed parents with lower odds of being captured; these nests therefore became control nests by default. In our design, there was a difference in the handling times of the birds in the different treatment groups. Indeed, handled birds with no deployed device were manipulated for less time than those in the tagged group (time was not measured), meaning that tag effects cannot be disentangled from handling time. However, the fact that we found no reduction in reproductive performance in the tagged group despite this added stress suggests that these gulls are not particularly sensitive to handling or tag deployment. Our study also did not reveal any significant interactions between body mass and treatment group that could have influenced the reproductive success of our birds. However, there did appear to be an effect of body mass on fledging success, with larger birds (and potentially higher-quality birds; Bolton 1991) having higher success in raising their offspring. However, no effect of relative device mass on reproductive success was detected.

In conclusion, we found no indication that wing-harnessed tracking devices affected the short-term reproductive success of Yellow-legged Gulls, regardless of their breeding colony. Considering outcomes on other gull species, our results suggest species-specific rather than colony-specific responses to logger deployment. However, although reproductive success varied among the studied colonies, all colonies performed relatively well. The inclusion of colonies suffering more adverse conditions may have revealed an interaction with logger deployment. To understand what factors drive species-specific impacts, it is crucial to continue investigating this matter in other species. As the weight of tracking devices declines with increasing technological advancements (Nathan *et al.* 2022), it will be particularly interesting to evaluate how these effects may change over time. In addition, most studies, including ours, only consider the impact of tracking devices on current reproductive success, but we still know little about their potential long-term effects on survival and life-time reproductive success; such studies should now start to be feasible and will be essential for evaluating the potential lag effects of carrying tracking devices. Indeed, such longer-term fitness effects may be provoked by the finer impacts of logger deployment on avian physiology or behaviour, as seen in other species (Elliott *et al.* 2012, Ludynia *et al.* 2012). By examining the potential impacts that tracking devices may have on monitored individuals, we not only help to clarify some of the ethical concerns associated with using these invasive techniques, but we also improve the quality of our research results. We therefore advocate integrating the evaluation of such impacts into all study designs that employ tracking devices.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

ETHICAL NOTE

Authorizations to capture, sample and tag birds were provided by the Ministère de l’Enseignement Supérieur, de la Recherche et de l’Innovation – France (no. AFIS#25183–2 020 090 713 423 689) and the Generalitat de Catalunya, Spain (no. 2022PNATMBTAUT005). Ringing was carried out under programme no. 990 of the CRBPO (MNHN, France).

AUTHOR CONTRIBUTIONS

Charly Souc: Conceptualization; methodology; investigation; writing – original draft; visualization; formal analysis; data curation; validation. **Carole Leray:** Conceptualization; methodology; investigation; writing – review and editing; validation; data curation. **Thomas Blanchon:** Methodology; investigation; validation. **Thomas Dagonet:** Investigation; validation. **Marion Vittecoq:** Conceptualization; supervision; writing – review and editing; funding acquisition; validation. **Raül Ramos:** Conceptualization; investigation; writing – review and editing; validation; funding acquisition. **Karen D. McCoy:** Conceptualization; methodology; investigation; supervision; writing – review and editing; funding acquisition; project administration.

DATA AVAILABILITY STATEMENT

The datasets generated and/or analysed during the current study are available in the Wedrop repository, (https://ftp.cx/dxg8cC) under the name: YLG_Reproduction_GPS.xlsx.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1. Details of the monitored Yellow-legged Gull nests from the four studied colonies.

Table S2. Post-hoc Tukey test results of pairwise comparisons of colony reproductive parameters for the response variables that exhibited a colony effect during model selections: (a) Hatching success, (b) Fledging success, (c) Number of fledged chicks.

Figure S1. Spatial distribution of treatment groups and their hatching /fledging success for each colony.

Table S3. Model selection results for the four measured reproductive parameters based on AICc, including the tested explanatory variables, with mass.

Table S4. Analysis of deviance (ANODEV) for models with ΔAICc <2 as presented in SOM3.

Table S5. Analysis of deviance (ANODEV) for models with relative mass as an explanatory variable.

Appendix S1. Power analysis conducted on the full models.