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1 **Testing for effects of tail mounted radio tags and environmental**
2 **variables on European Nightjar (*Caprimulgus europaeus*) nest survival**

3

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13

14 **Keywords:** Radio tag, Nightjar, Nest survival

15

16 **Short Title:** Effects of radio tags on Nightjar nest survival

17

18

19 **Summary**

20 Capsule – Monitoring of European Nightjar *Caprimulgus europaeus* nest sites over
21 multiple years (2013-2019) produced no evidence of a negative effect of tail-mounted
22 radio tag deployment on nest success.

23 Aims – To test whether nest success of European Nightjar was affected by radio tag
24 deployment.

25 Methods – The breeding parameters of European Nightjar were monitored at the
26 Brechfa West Wind Farm, Carmarthenshire, Wales, from 2013 to 2019. A total of 85
27 nests were located through a combination of capture and radio tracking of breeding
28 individuals, and direct observation combined with focused searching. All located nests
29 were subsequently monitored through a combination of visual checks and trail camera
30 deployment until their natural conclusion.

31 Results – No evidence was identified to support a negative effect of tail mounted radio
32 tag deployment on the nest success of European Nightjar. However, nesting success (1
33 or more chicks fledged) was positively associated with mean temperature during the
34 nesting period, although the strength of this effect varied through time.

35 Conclusion – The use of tail mounted radio tags on European Nightjar has no negative
36 effect on nest survival.

37 **Introduction**

38 The marking and tagging of birds are widespread and important methods that have
39 informed studies of many aspects of animal ecology, including migration, foraging
40 behaviour and physiological ecology (Bodey et al. 2017). The techniques used for such
41 marking are continuously evolving, and have been used in some form for many decades.
42 The extra mass that these devices impose, the tag configuration and attachment method
43 used has, however, been a cause for concern, especially for relatively heavy devices
44 such as radio tags, GPS devices and geolocators (e.g. Bowlin et al. 2014). The
45 deployment of such devices has been shown in some cases to reduce survival, inhibit
46 parental care (Bodey et al. 2017), induce potentially costly behavioural modifications
47 (Vandenabeele et al. 2014), or reduce the probability of nesting (Barron et al. 2010).
48 Several mechanisms for such effects have been identified including; increased energetic
49 costs of flight through drag (Bowlin et al. 2010), reduced foraging success (Wanless et
50 al. 1988), impacts on young through reduced provisioning (Robert et al. 2006) and
51 increased thermoregulatory costs due to feather loss and skin damage (Hines and
52 Zwickle 1985). Although it is likely that such affects are in many cases species specific
53 with other studies identifying few, if any effects (e.g. Bell et al. 2017, Brlik et al. 2020).
54 In an attempt to overcome such device effects, the research community has adopted
55 rules of thumb for the design of tagging studies, such as the '5% rule'. This dictates a
56 maximum tag mass limit of 5% of a bird's body mass (Brander & Cochran 1969). The
57 figure of 5% has been considered too high by some authors or for some taxa; for
58 example Kenward (2001) suggested a limit of no more than 3%, supported by studies of
59 nest abandonment in albatross and petrel species (Phillips et al. 2003, Casper 2009).
60 In recent years, further research has shown a simple percentage mass rule of thumb is

61 likely to be over-simplified. For example, various studies have shown that factors such
62 as device-induced drag (Vandenabeele et al. 2013), tag shape and attachment location
63 (Kay et al. 2019) are also critical considerations. These considerations, coupled with the
64 apparently species-specific nature of tag effects, highlight the importance of testing for
65 tagging impacts on individual species.

66 European Nightjar *Caprimulgus europaeus* (henceforth “nightjar”) breeding in Welsh
67 upland coniferous forest, are difficult to monitor using conventional survey techniques
68 due to their crepuscular nature, cryptic camouflage, and low density population (Cross
69 et al. 2005, Gilbert et al. 1998). Therefore, a combination of radio tracking and
70 observational nest finding methods have generally been utilised together for such
71 studies at upland sites in Wales.

72 Radio transmitters and GPS devices suitable for deployment on nightjar have been
73 available for some time, and have been widely used in breeding studies, most often as
74 tail mounted devices (e.g. Alexander et al. 1990, Cross et al. 2005, Evens et al. 2018).
75 Despite their widespread use in studies of breeding nightjars (e.g. Sharps et al. 2015,
76 Evens et al. 2017) there is to our knowledge no published study of the effects of such
77 tag deployment on breeding success. It is, however, critical that such effects should be
78 investigated so that risks can be evaluated and minimised (Wilson et al. 2006, Casas et
79 al. 2015).

80 An additional challenge in evaluating tag effects is to distinguish them from
81 environmental impacts on survival or breeding success due to factors such as habitat
82 quality or weather. Previous studies on nest survival in nightjars have identified
83 probable effects of weather on nest survival (English et al. 2018) and similar effects are
84 widely documented from studies in other species (e.g. Miller et al. 2017, Martin et al.

85 2017). As such, it is critical in studies of tag effects to account for such variables to
86 accurately gauge any evidence of effects. In the present study, we therefore considered
87 tag effects together with a set of environmental variables that we hypothesised may
88 influence nightjar breeding success.

89 The present study directly compares observed nesting success of tagged birds and
90 untagged birds, in order to investigate the potential effects of tag deployment and
91 environmental variables on nesting nightjars. These data have been collected as part of
92 on-going ecological impact monitoring requirements associated with the Brechfa West
93 Wind Farm development. The data set includes nest record data from the study site
94 during the pre-development, construction and operational phases of the wind farm.

95 **Methods**

96 *Study Species*

97 Nightjars are ground nesting birds that typically lay two eggs (occasionally one egg)
98 and usually produce two broods per breeding season (Holyoak et al. 2001). The nightjar
99 is usually thought of as a heathland species, but in Wales they mainly breed in clear-fell
100 forestry (i.e. recently felled forestry, before substantial re-planting / re-growth), check
101 coupes (i.e. stands of stunted tree growth) and recently restocked conifer plantations
102 (Conway et al. 2007). Male nightjars establish breeding territories within the study area
103 in May; females arrive in mid-May and subsequently become paired with established
104 territorial males.

105 Nightjars are of conservation concern due to historic population declines and range
106 contraction (Balmer et al. 2013, Hagemeyer & Blair 1997). The nightjar is an Annex 1
107 species in the EU (Council Directive 2009/147/EC), has Amber status in the UK (Bird

108 of Conservation Concern; Eaton et al. 2015) and is listed under Section 7 of the
109 Environment (Wales) Act 2016. The nightjar population in Wales has been increasing
110 since at least 1981 (Morris et al. 1994), possibly due to increased habitat availability
111 following the maturation and felling of plantations that were planted in the 1950's.

112 ***Study Site***

113 This study utilises nest data from Brechfa Forest (South Wales, UK – Latitude
114 51.967432, Longitude -4.1964175), a commercial plantation forestry managed by
115 Natural Resources Wales on behalf of Welsh Government. The forest is dominated by
116 dense Sitka Spruce *Picea sitchensis* forest blocks (coupes), interspersed with recently
117 felled areas around wind turbines, and with semi-natural woodland along watercourses.

118 Topography and forest age at this site has enabled observational nest finding to be
119 relatively successful during recent commercial ecological monitoring work.

120 ***Nest data collection***

121 The inclusion of nightjar in species protection legislation ensures that nightjar nest
122 locations are protected from damage/ destruction under the Wildlife and Countryside
123 Act (1981). Suitably licensed and experienced individuals undertook all tagging and
124 nest monitoring visits completed in this study.

125 ***Territory identification***

126 Active territories were located by systematic searches in areas of suitable habitat, and
127 were confirmed by observation of pairs or of displaying males, which produce a
128 distinctive “churring” call (Ferguson-Lees et al. 2011).

129 ***Observational nest location***

130 Nest searching commenced annually in late May, and continued until August. Active
131 territories were systematically watched on multiple occasions by multiple observers at
132 dusk, and visual cues were used to guide follow up nest searches (Langston et al. 2009).
133 Subsequent nest searches consisted of detailed visual inspection in areas of observed
134 nightjar activity during dusk watches, with searchers aiming to pass within 3-4 metres
135 of any point within the search area.

136 ***Radio tracking nest location***

137 Where observation of active nightjar territories yielded little information, or nest
138 searches were unsuccessful, or where pairs were considered likely to attempt a 2nd
139 brood, then these territories/ pairs were targeted for radio tagging effort. Mist nets were
140 set up in the vicinity of identified territories, and male nightjars were then tape lured
141 into the mist nets by playing the species' typical territorial song (Squire and Alexander
142 1981). Tape luring proved less effective at attracting incubating females. Females were
143 caught by mist-netting at favoured feeding sites, or by trapping at known 1st brood nests
144 (found by field observation) to allow radio tracking to 2nd brood nests.

145 Captured birds were fitted (under licence) with PIP-3 radio-transmitters (from Lotek Ltd
146 – as per Alexander and Cresswell (1990)), attached to the base of one of the central tail
147 feathers. Attaching the radio-transmitters in this way ensures that they are shed during
148 post-breeding moult in the wintering grounds, and thus does not affect the birds during
149 their spring migration. The tags used in this study each weighed 1.2g, male nightjars
150 weighed between 60.2–87.0 g (n=34), and females weighed between 69.0–100.8 (n=23)
151 - so tags weighed 1.34–1.99% of male body weight, and 1.19–1.72% of female body
152 weight.

153 Tags were deployed across the breeding season, with tagging dates ranging between the
154 3rd of June and 24th of July. The median tagging date was the 25th of June; the mean
155 tagging date was the 25th of June for females and 27th of June for males. Tags were
156 deployed both prior to and after nests were located; 19 of the 39 tagged females were
157 tagged after their nest was located, as were 11 of the 25 tagged males.

158 Following the identification of active nests through either observation or radio tracking,
159 all nests were monitored to their natural completion (fledging or nest failure) by an
160 experienced nightjar fieldworker, using regular (~weekly) nest site visits. Nests were
161 classified as either successful or failed, based on a combination of the timing of nest
162 visit records and available evidence at the nest site and within the territory (i.e. flying
163 young present).

164 ***Weather data***

165 In order to account for the influence of weather on nesting success, data from the closest
166 available weather station (Pembrey; 51.7144117°N, -4.366197°E, approximately 30km
167 south of the study site) was obtained using the GSODR package (Sparks, Hengl, and
168 Nelson 2017) using R software version 3.6.1 (R Core Team 2019), implemented via R
169 Studio (RStudio team 2018). The GSODR package provides automated downloading,
170 parsing and cleaning of Global Surface Summary of the Day (GSOD) (United States
171 National Oceanic and Atmospheric Administration National Climatic Data Center)
172 weather data. This provided daily rainfall (mm) and mean temperature (T_m, °C). Data
173 manipulation and visualisation was undertaken using the R libraries tidyverse
174 (Wickham et al. 2019), lubridate (Groelmund & Wickham 2011) and ggplot2
175 (Wickham, 2016). Mean temperature and mean precipitation were calculated for the

176 active period of each nest (laying date to last known presence) and utilised in
177 subsequent analysis.

178 *Statistical analysis*

179 We performed all statistical analyses in R 3.6.0 (R Core Team 2019). In order to
180 account for the inherent bias in nest studies arising from the lower detection probability
181 of failed nests (due to their shorter time available for potential observation), we
182 estimated daily nest survival rates - DSR (Mayfield 1975, Dinsmore et al. 2002) using
183 RMark version 2.2.7 and MARK (Laake 2013, White and Burnham 1999).

184 Daily nest survival rates were estimated and modelled with selected covariates using the
185 R package RMark version 2.2.7 (Laake 2013). We undertook model selection of nest
186 survival models using an information theoretical approach based on the second-order
187 Akaike information criterion for small sample sizes (AICc; Burnham and Anderson
188 2002).

189 A set of 193 biologically plausible models was derived, including additive effects of
190 Julian day, nest age (as estimated based on hatch date, if available, or if not then using
191 estimates based on egg floatation (Westerskov 1950) or observational information),
192 brood (1st, 2nd, 3rd), year, mean rainfall within the relevant active nest period, mean
193 temperature (T_m) within the relevant active nest period, the presence of windfarm
194 construction activity (binary yes/no – nest active in year of construction activity), adult
195 male tag status (tag status of the male associated with nest - binary yes/ no), adult
196 female tag (tag status of the female associated with nest - binary yes/ no) and combined
197 adult tag status (tag status of both adults associated with nest - binary yes/ no - i.e. both
198 birds tagged or not). The candidate models also included the interaction between mean
199 temperature and date, to help distinguish the effect of temperature from seasonality. The

200 combined adult tag status variable was included to account for potential synergistic
201 effects of tagging both parents. All covariates were scaled prior to analysis, to have a
202 mean of zero and a standard deviation of one. The set of candidate models also included
203 a global model (containing all candidate independent variables) and a null model
204 (containing no independent variables). Co-linearity between variables was determined
205 using Pearson's correlation coefficient, and this identified low levels of correlation
206 between candidate model variables. No candidate model variables exceeded the
207 threshold correlation of 0.7 (Dorman et al. 2013) and all candidate variables were thus
208 included in the analysis.

209 Models were ranked using AICc, and the Δ AICc values and Akaike weights (w_i) were
210 used to infer support for each of the candidate models (Appendix A). In our model
211 selection analysis, no single model was clearly better than all others, and to account for
212 model selection uncertainty, models within two AICc units of the top model, were
213 selected for model averaging, as this can provide a robust means of obtaining parameter
214 estimates in such scenarios (Burnham & Anderson 2002, Grueber et al. 2011, Harrison
215 et al. 2018). A weighted average of the parameter estimates (and 95% confidence limits)
216 was calculated for all of the variables contained in the top models, using the package
217 MuMIn (Grueber et al. 2011, Barton 2018, Mwangi et al. 2018) (Table 2). Parameters
218 were considered statistically significant where their model-averaged 95% confidence
219 limits did not span zero.

220 Overall nest survival was calculated from predictions daily of nest survival rate (DSR)
221 made by the final, averaged model. These were converted to the overall nest success by
222 assuming a 36 day standard nesting period (DSR^{36}) from the median nest initiation
223 date. Variance in the nest survival estimates were obtained using the delta method
224 (Powell 2007).

225 The same suite of models was also re-run using a subset of the data representing the egg
226 stage and chick stage respectively. Whilst this reduced the sample size for these models,
227 it was considered to potentially provide greater insights into potential tag effects during
228 the two different breeding stages, given the likely different energetic demands and
229 behaviours associated with each stage. Due to convergence problems, because of small
230 sample sizes, the chick stage models were run without the year parameter.

231 **Results**

232 *Nest finding and monitoring*

233 Eighty five nightjar nests were located over the course of the study (2013-2019); sixty-
234 one of these were located through direct observation of adult behaviour, and twenty four
235 were located using radio tracking. Median nest initiation date was 16th June (range =
236 27th May – 27th July). In total, 59 nests were confirmed first brood nests and 13
237 confirmed second brood nests. Two nest attempts were also recorded as ‘third brood’
238 nests, although these were a result of early failure of previous nesting attempts (1st or
239 2nd brood) and thus are replacement clutches; they have nevertheless been referred to as
240 third brood nests for the ease of reference. Brood number could not be confirmed at 11
241 of the located nests.

242 We found nests at different stages of development: 52 (61.1%) during incubation and 33
243 (38.8%) were found during the nestling period. From all of the nests, 52 fledged at least
244 one chick, whilst the remainder (33) failed, with 15 at the egg stage and 18 failing at the
245 chick stage. A summary of nest success and the number of nests with attending tagged
246 adults is provided in Table 1, whilst Table 2 details the breakdown of nests attended by
247 tagged adults, by adult sex, and brood number.

248 *Nest survival*

249 In our model selection analysis, there were three models within 2 AIC units and they
250 contained the following variables – nest age, female tag status, adult tag status,
251 temperature, precipitation and Julian day (Table 1). In order to account for model
252 selection uncertainty, a conditional weighted average (averaged over only the models
253 containing those parameters) and a full weighted average (all models using zero value
254 for parameters not present) of the parameter estimates and 95% confidence limits was
255 calculated for all of the variables contained in the top three models (conditional
256 weighted averages in Table 4, and full weighted averages in Table 5). Full weighted
257 model average parameter estimates are reported below, along with the standard error
258 (SE).

259 Estimated average daily nest survival (\pm SE), across all years and tag treatments, was
260 0.986 (\pm 0.008). This extrapolates over the 36-d nesting cycle to an average annual nest
261 success rate of 0.63 (\pm 0.18).

262 The same suite of models run on subsets of the full data set for the egg stage of the
263 nesting cycle failed to identify any parameters as having an important effect on DSR
264 and identified no detectable difference between DSR for tagged nests vs. untagged nests
265 at either stage. Top selected models and model averaged coefficients for the identified
266 top models are presented in supplementary materials Appendix B – Table B1 to Table
267 B3. The same suite of models for the chick stage of the nesting cycle failed to converge
268 due to low sample sizes.

269 ***Radio tag effects***

270 There was no evidence for tags reducing nesting success. Although two of the three top
271 models of daily nest survival rate included either female tag status or adult tag status
272 variables, these all indicated a positive relationship that was not significant: a result
273 confirmed by the averaged model ($\beta_{fm_tag} = +0.158 \pm 0.429$; $\beta_{f_tag} = +0.445 \pm$
274 0.499).

275 Overall DSR rates for untagged female attended nests and tagged female attended nests
276 were $0.984 (\pm 0.010 [SE])$ and $0.990 (\pm 0.006 [SE])$ respectively (Figure 1). Estimated
277 DSR for untagged and tagged adult attended nests (male or female) were very similar, at
278 $0.986 (\pm 0.010)$ and $0.991 (\pm 0.006)$ respectively (Figure 2).

279 ***Nest age and Julian day***

280 The top model of daily survival rate included significant effects of Julian day and nest
281 age (initiation date; Table 3). Nest survival rate of nightjar decreased as the season
282 progressed (model-averaged parameter \pm SE; $\beta_{\text{Julian day}} = -0.07 \pm 0.023$) but
283 increased with the age of the nest ($\beta_{\text{nest initiation date}} = +0.072 \pm 0.028$). Over the
284 nesting season, model averaged DSR ranged from $0.988 (\pm 0.012)$ on day 1 of the
285 nesting season (28th May), to $0.986 (\pm 0.013)$ on day 81 (17th August).

286 ***Weather effects***

287 Initial data exploration of weather data identified a weak positive correlation between
288 relative humidity (surrogate for cloud cover) and minimum temperature ($\tau = 0.177$),
289 with a similar positive correlation noted between relative humidity (surrogate for cloud
290 cover) and minimum temperature ($\tau = 0.219$). As such, weather effects should be
291 interpreted in this context.

292 The top models together provide good evidence that temperature has an important effect
293 on nest success, as temperature was consistently selected in top models. Alternative
294 models without this variable did not receive strong statistical support and were at least
295 2.7 AICc units from the top model.

296 Average temperatures during active nest periods over the study years ranged from 12.8
297 to 19.5 °C, and model predictions showed a positive relationship with temperature (β
298 $m_temp = +2.501 \pm 1.083$; Table 5). As confidence intervals did not include zero, this is
299 considered a statistically significant effect. The top models also consistently
300 incorporated an interactive effect between temperature and Julian day on DSR, and this
301 interaction term appeared in all top models.

302 Model estimates show a negative parameter for the temperature x Julian day interaction
303 term ($\beta m_temp: Time = -0.035 \pm 0.019$; Table 5). As confidence intervals include zero
304 this is however not considered to be a statistically significant interaction. Despite this,
305 the important effects of temperature on DSR must be viewed in the context of its
306 relationship with time, as its inclusion in top models suggests that the magnitude of the
307 positive effect temperature is potentially conditioned on Julian day. This interaction
308 term describes how the effect of temperature varies through time, and indicates that the
309 positive effect of temperature on DSR depends on the Julian day and decreases through
310 the breeding season. This may be due to threshold effects of temperature, as temperature
311 exhibits a non-linear relationship with time through the season, or could be due to
312 further interactions with the stage of nest development – i.e. nests are more likely to
313 have chicks later in the season.

314 Predicted DSR increased from 0.36 (95% CI 0.03 to 0.920) to 0.999 (95% CI 0.994 to
315 0.999) over the recorded temperature range (12.8 to 19.5 °C), for a nest initiated on the

316 16th June (median date of nest initiation) assuming average values for the other
317 covariates (Figure 3).

318 Mean daily rainfall during the active nest periods ranged from 0 mm to 10.55 mm, with
319 a mean of 2.10 mm. No significant effect of precipitation on DSR was detected (β
320 m_prcp 0.509 ± 0.382 , Table 5); confidence intervals for this estimate spanned zero,
321 suggesting a lack of any statistically significant effect.

322

323 **Discussion**

324 Mean temperature and nest age were identified as important factors associated with
325 annual reproductive success of nightjars at the study site (see Table 2 and Table 3). No
326 evidence for a negative effect of tagging was identified by the models of nest survival,
327 and this is consistent with the raw data, where mean nest success across the seven years
328 of the study was 61% for nests attended by one or two tagged parents, and 62% for
329 nests attended by untagged parents. This provides good evidence that the continued use
330 of radio tagging to facilitate nest finding is unlikely to impact nest survival.

331 Models identified no evidence that any of the other candidate variables affected nesting
332 success, with no statistically significant effect noted for Julian day, precipitation, brood
333 or year of construction. Previous studies of nightjar nest success have focused on the
334 effects of recreational disturbance (e.g. Langston et al. 2007; Lowe et al. 2014) and in
335 general have identified a negative effect of such disturbance, but have not investigated
336 relationships with tagging, time or weather. Langston et al. (2007) estimated overall
337 nesting success to be 39% in the Dorset heathlands, whereas Lowe et al. (2014)
338 estimated success at 53% in Nottinghamshire plantation forestry sites. Overall nest
339 success estimates of 61-62% from the upland forestry habitats of the Brechfa Forest
340 study site thus compare favourably with reported nest success rates from other studies.

341 A significant effect of nest age on daily survival rate was identified, with DSR
342 increasing with nest age within individual breeding attempts. Similar variation in chick/
343 nest survival with age has been observed in other species (e.g. Grant et al. 2005,
344 McDonald et al. 2016, English et al. 2018, Maziarz et al. 2019, Zhao et al. 2020). The
345 positive pattern noted here could be due to older chicks having greater resilience to poor
346 weather and being more able to overcome the nutritional and thermoregulatory burden

347 of poor weather, as has been suggested for Northern Bobwhite chicks (*Colinus*
348 *virginianus* – Terhune et al. 2019).

349 The identified positive association between temperature and nest survival is
350 unsurprising, as during periods of low temperature nests can fail due to chick starvation
351 (pers, obs) and similar positive effects of temperature have been made in North
352 American nightjar species - whip-poor-will (*Antrostomus vociferous* - English et al.
353 2018). In general, young, downy chicks are likely to be less able to thermally regulate
354 effectively (Du Rant et al. 2001, Newberry et al. 2018), and thus may be particularly
355 vulnerable to adverse weather and predation. Young chicks will repeatedly call when
356 chilled; this advertisement is likely to increase predation risk as has been observed in
357 other bird species (e.g. Deardon 1999, Briskie et al. 1999, Ibanez-Alamo et al. 2012,
358 Husby 2019, Gonchorova et al. 2019), and may form part of the mechanism by which
359 low temperature leads to nest failure. In addition, moth activity is generally positively
360 correlated with temperature (Holyoak et al. 1997), so a direct negative effect of cold
361 weather on nest success through reduced food availability, would be expected though
362 direct impacts on provisioning at the chick stage, or indirectly through reduced
363 incubation intensity at the egg stage. Similar effects of temperature on chick survival
364 have also been noted in a North American nightjar species (the Whip-Poor-Will -
365 *Antrostomus vociferus*, English et al. 2018) with higher chick survival recorded on
366 warmer nights.

367 It is surprising, however, that rainfall did not show a negative effect on nest survival, as
368 nest failure due to hypothermia/starvation has previously been recorded following
369 protracted heavy rain (pers. obs), and moth activity is generally negatively correlated
370 with rainfall (Holyoak et al. 1997). One explanation may be the presence of a positive
371 correlation between the minimum daily temperature (likely at night) and rainfall (tau =

372 0.177), as during cloudy conditions night-time temperatures are usually higher than
373 under clear skies. This may be particularly relevant for the dawn foraging period for
374 nightjars, when at 300m elevation (as at the study site), the temperature is often below
375 10°C following a night of clear skies during the main breeding season (See Appendix C
376 – Figure C1 and C2). Hence it may be that extreme rainfall events have a negative effect
377 by causing direct chick mortality, as has been shown in White Stork (*Ciconia ciconia* -
378 Tobolka et al. 2015) and Northern Wheatear (*Oenanthe oenanthe* - Oberg et al. 2015),
379 but food availability is perhaps increased both when evenings are warm following
380 sunny weather, and during cloudy, drizzly conditions, when both dusk and dawn
381 foraging periods are relatively mild. This increase in food availability may lead to
382 improved nest survival, as has been noted in other species (White Ibis *Eudocimus albus*
383 - Herring et al. 2011, and Eurasian reed warbler *Acrocephalus scirpaceus* - Vafidis et al.
384 2016). However, more work is needed in this area, including collecting insect
385 abundance data, to try to unpick the relationships between weather, insect abundance
386 and nest survival (Shewring et al. in prep.).

387 Wind farm construction had no observable effect on the daily nest survival rate, and the
388 year of construction variable was not selected in any of the top models. It is, however,
389 worth noting that any effects of construction disturbance are likely to be influenced by
390 the proximity of individual nests to construction activity. Such detailed data were not
391 available to inform the current study, but would certainly be recommended in future
392 studies focused on the effects of construction disturbance. In addition, there were
393 deliberate attempts to limit construction effects on nightjar at the Brechfa windfarm
394 (e.g. by using disturbance exclusion buffers around located nests) and as such, this
395 conclusion is only relevant to construction where such mitigation procedures are
396 implemented. In light of this, we would advise that this aspect of the analysis be treated

397 with the appropriate caution when interpreting the sensitivity of nightjar to construction
398 disturbance.

399 It should however be noted that nest survival is a single metric for impact identification
400 of tagging, and other effects of tag deployment on nightjar cannot be discounted based
401 on the current study. It is certainly possible that tagging has affected foraging success
402 and ranging behaviour, as has been noted in other species (e.g. Taylor et al 2001,
403 Phillips et al. 2003), but any such effects have not fed through to detectable effects on
404 nest survival. As such, we would recommend further study of tag effects in nightjar,
405 especially where tagging is proposed for longer durations or where heavier tags are
406 proposed.

407 In conclusion, the current study confirms the importance of weather effects on nightjar
408 nest survival, particularly the positive effect of temperature. It also confirms the lack of
409 observable tagging effects on nest survival when using tail mounted radio tags, and
410 indicates that their continued use in nest finding studies is unlikely to have a negative
411 impact on nest survival. Integrating these two conclusions leads us to recommend that
412 future tagging studies adequately consider potentially confounding weather effects.

413

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610

611 **Appendix A**

612 **Table A1.** All candidate models of nightjar daily nest survival rates, for a set of
 613 independent variables comprising: total rainfall (s_prcp), average temperature
 614 (m_temp), nest age (NestAge), time, construction year (ycons), adult female tag
 615 status (f_tag), adult male tag status (m_tag), both adult tag status (fm_tag), adult
 616 male or female tag status (f_m_tag) and year (2013 to 2019).

617

Model	nPar	AICc	DeltaAICc	weight	Deviance
S(~NestAge + f_tag + m_temp * Time + m_prcp2)	7	170.11	0.00	0.12	156.02
S(~NestAge + fm_tag + m_temp * Time + m_prcp2)	7	171.27	1.15	0.07	157.17
S(~NestAge + m_temp * Time + m_prcp2)	6	171.86	1.75	0.05	159.79

S(~NestAge + f_tag + m_temp * Time)	6	172.46	2.35	0.04	160.39
S(~NestAge + f_tag + Time * m_temp + m_prcp2 + brood1 + brood2 + brood3)	10	172.96	2.84	0.03	152.77
S(~NestAge + fm_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp * Time + m_prcp2)	14	173.35	3.23	0.02	144.99
S(~NestAge + fm_tag + y13 + y14 + y15 + y16 + y17 + y18 +	14	173.35	3.23	0.02	144.99

y19 + m_prpc2 + Time * m_temp)					
S(~NestAge + fm_tag + m_temp * Time)	6	173.40	3.29	0.02	161.33
S(~NestAge + f_tag + brood1 + brood2 + brood3 + Time * m_temp)	9	173.53	3.42	0.02	155.38
S(~NestAge + f_tag + m_temp + m_prpc2 + Time)	6	173.58	3.47	0.02	161.51
S(~NestAge + f_tag + Time)	4	173.60	3.49	0.02	165.57
S(~NestAge + m_temp * Time)	5	173.66	3.55	0.02	163.61

S(~f_tag + Time)	3	173.80	3.69	0.02	167.78
S(~NestAge + f_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp * Time + m_prp2)	14	173.80	3.69	0.02	145.45
S(~NestAge + f_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_prp2 + Time * m_temp)	14	173.80	3.69	0.02	145.45
S(~NestAge + m_tag + m_temp * Time + m_prp2)	7	173.88	3.76	0.02	159.78

S(~NestAge + fm_tag + Time)	4	173.94	3.82	0.02	165.90
S(~fm_tag + Time)	3	173.96	3.85	0.02	167.94
S(~NestAge + fm_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp * Time)	13	174.19	4.08	0.02	147.88
S(~NestAge + fm_tag + m_temp + m_prp2 + Time)	6	174.20	4.09	0.02	162.13
S(~NestAge + m_temp + m_prp2 + Time)	5	174.34	4.23	0.01	164.29

S(~f_tag + m_temp * Time)	5	174.41	4.29	0.01	164.35
S(~NestAge + f_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp * Time)	13	174.49	4.38	0.01	148.18
S(~NestAge + fm_tag + Time * m_temp + m_prcp2 + brood1 + brood2 + brood3)	10	174.50	4.38	0.01	154.31
S(~NestAge + fm_tag + brood1 + brood2 + brood3 + Time * m_temp)	9	174.82	4.70	0.01	156.66
S(~fm_tag)	2	175.00	4.89	0.01	170.99

S(~f_tag + NestAge * m_temp * Time)	9	175.01	4.90	0.01	156.86
S(~fm_tag + m_temp * Time)	5	175.09	4.97	0.01	165.04
S(~NestAge + Time * m_temp + m_prcp2 + brood1 + brood2 + brood3)	9	175.29	5.17	0.01	157.13
S(~f_tag + m_prcp2 + m_temp * Time)	6	175.37	5.26	0.01	163.30
S(~NestAge * m_temp * Time)	8	175.45	5.34	0.01	159.33
S(~f_tag)	2	175.48	5.36	0.01	171.47
S(~NestAge * Time + m_temp + m_prcp2)	6	175.50	5.39	0.01	163.43

S(~NestAge + brood1 + brood2 + brood3 + Time * m_temp)	8	175.55	5.43	0.01	159.42
S(~NestAge + m_tag + m_temp * Time)	6	175.68	5.57	0.01	163.61
S(~NestAge + Time)	3	175.70	5.58	0.01	169.68
S(~fm_tag + NestAge * m_temp * Time)	9	175.72	5.61	0.01	157.57
S(~NestAge * m_temp * Time + fm_tag)	9	175.72	5.61	0.01	157.57
S(~NestAge + f_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp +	13	175.87	5.75	0.01	149.55

m_prcp2 + Time)					
S(~Time)	2	175.89	5.77	0.01	171.88
S(~NestAge + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp * Time + m_prcp2)	13	175.92	5.80	0.01	149.61
S(~NestAge + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_prcp2 + Time * m_temp)	13	175.92	5.80	0.01	149.61
S(~m_temp * Time)	4	176.09	5.98	0.01	168.06
S(~fm_tag + m_prcp2 + m_temp * Time)	6	176.15	6.04	0.01	164.08

S(~NestAge + fm_tag)	3	176.32	6.21	0.01	170.30
S(~NestAge + m_tag + m_temp + m_prcp2 + Time)	6	176.36	6.25	0.01	164.29
S(~NestAge * Time + m_temp + brood1 + brood2 + brood3)	8	176.48	6.37	0.01	160.36
S(~f_tag + m_temp + m_prcp2 + Time)	5	176.54	6.42	0.00	166.49
S(~NestAge + f_tag + m_temp + m_prcp2 + Time + brood1 +	9	176.55	6.44	0.00	158.40

brood2 + brood3)					
S(~NestAge + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp * Time)	12	176.62	6.50	0.00	152.35
S(~1)	1	176.65	6.54	0.00	174.65
S(~fm_tag + m_temp + m_prcp2 + Time)	5	176.91	6.80	0.00	166.86
S(~NestAge + f_tag)	3	176.91	6.80	0.00	170.89
S(~NestAge + f_tag + Time + brood1 + brood2 + brood3)	7	177.04	6.93	0.00	162.95

S(~NestAge * Time)	4	177.12	7.01	0.00	169.09
S(~NestAge + fm_tag + m_temp + m_prcp2 + Time + brood1 + brood2 + brood3)	9	177.14	7.03	0.00	158.99
S(~NestAge + m_tag + Time * m_temp + m_prcp2 + brood1 + brood2 + brood3)	10	177.25	7.14	0.00	157.07
S(~m_prcp2 + m_temp * Time)	5	177.31	7.19	0.00	167.25
S(~NestAge + m_temp + m_prcp2 + Time + brood1 +	8	177.37	7.25	0.00	161.24

brood2 + brood3)					
S(~f_tag + m_temp * Time + m_prcp2 + ycons)	7	177.38	7.26	0.00	163.28
S(~f_tag + m_prcp2 + ycons + Time * m_temp)	7	177.38	7.26	0.00	163.28
S(~NestAge + m_tag + brood1 + brood2 + brood3 + Time * m_temp)	9	177.39	7.27	0.00	159.24
S(~NestAge + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp +	12	177.39	7.28	0.00	153.13

m_prcp2 + Time)					
S(~m_tag + NestAge * m_temp * Time)	9	177.48	7.36	0.00	159.33
S(~NestAge * m_temp * Time + m_tag)	9	177.48	7.36	0.00	159.33
S(~ycons + NestAge * m_temp * Time)	9	177.48	7.37	0.00	159.33
S(~NestAge + fm_tag + Time + brood1 + brood2 + brood3)	7	177.53	7.42	0.00	163.44
S(~fm_tag + m_temp * Time + m_prcp2 + ycons)	7	177.62	7.50	0.00	163.52

S(~fm_tag + m_prcp2 + ycons + Time * m_temp)	7	177.62	7.50	0.00	163.52
S(~ycons + Time)	3	177.66	7.54	0.00	171.64
S(~NestAge + m_tag + Time)	4	177.67	7.56	0.00	169.64
S(~NestAge + m_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp * Time + m_prcp2)	14	177.74	7.62	0.00	149.38
S(~NestAge + m_tag + y13 + y14 + y15 + y16 + y17 + y18 +	14	177.74	7.62	0.00	149.38

y19 + m_prcp2 + Time * m_temp)					
S(~m_tag + Time)	3	177.88	7.77	0.00	171.86
S(~f_tag + brood1 + brood2 + brood3 + Time * m_temp)	8	177.95	7.84	0.00	161.83
S(~NestAge)	2	177.97	7.85	0.00	173.96
S(~NestAge + f_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + Time * m_temp + m_prcp2 + brood1 + brood2 + brood3)	17	178.09	7.97	0.00	143.56
S(~ycons + m_temp * Time)	5	178.10	7.98	0.00	168.05

S(~m_tag + m_temp * Time)	5	178.11	7.99	0.00	168.06
S(~NestAge + m_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp * Time)	13	178.24	8.12	0.00	151.93
S(~f_tag + m_temp + m_prcp2 + ycons + Time)	6	178.37	8.25	0.00	166.29
S(~f_tag + Time + brood1 + brood2 + brood3)	6	178.44	8.32	0.00	166.36
S(~fm_tag + m_temp + m_prcp2)	4	178.53	8.42	0.00	170.50

S(~NestAge + fm_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + Time * m_temp + m_prpc2 + brood1 + brood2 + brood3)	17	178.55	8.43	0.00	144.02
S(~fm_tag + Time + brood1 + brood2 + brood3)	6	178.58	8.46	0.00	166.51
S(~m_tag)	2	178.66	8.54	0.00	174.65
S(~ycons)	2	178.66	8.54	0.00	174.65
S(~fm_tag + m_temp + m_prpc2 + ycons + Time)	6	178.91	8.79	0.00	166.83

S(~f_tag + m_temp + m_prp2)	4	178.95	8.84	0.00	170.92
S(~m_temp * Time + m_prp2 + ycons)	6	179.10	8.98	0.00	167.02
S(~m_temp + m_prp2 + ycons + Time * m_temp)	6	179.10	8.98	0.00	167.02
S(~NestAge + m_tag + m_temp + m_prp2 + Time + brood1 + brood2 + brood3)	9	179.31	9.19	0.00	161.15
S(~m_tag + m_prp2 + m_temp * Time)	6	179.32	9.21	0.00	167.25

S(~NestAge + fm_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp + m_prcp2 + Time + brood1 + brood2 + brood3)	16	179.35	9.24	0.00	146.89
S(~NestAge * Time + fm_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19)	12	179.37	9.25	0.00	155.10
S(~f_tag + Time * m_temp + m_prcp2 + brood1 + brood2 + brood3)	9	179.51	9.39	0.00	161.36
S(~NestAge + f_tag + y13 + y14 + y15 + y16	16	179.75	9.64	0.00	147.29

+ y17 + y18 + y19 + m_temp + m_prp2 + Time + brood1 + brood2 + brood3)					
S(~+m_temp + m_prp2 + ycons + Time)	5	179.77	9.65	0.00	169.72
S(~m_tag + m_temp + m_prp2 + Time)	5	179.77	9.66	0.00	169.72
S(~f_tag + brood1 + brood2 + brood3)	5	179.81	9.70	0.00	169.76
S(~NestAge + Time + brood1 + brood2 + brood3)	6	179.81	9.70	0.00	167.74

S(~NestAge + m_tag)	3	179.98	9.86	0.00	173.96
S(~NestAge + fm_tag + m_temp + m_prcp2)	5	180.08	9.96	0.00	170.03
S(~NestAge + fm_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + Time)	11	180.09	9.98	0.00	157.87
S(~m_temp + m_prcp2)	3	180.10	9.99	0.00	174.08
S(~fm_tag + Time * m_temp + m_prcp2 + brood1 + brood2 + brood3)	9	180.47	10.35	0.00	162.31
S(~fm_tag + m_temp +	5	180.55	10.44	0.00	170.50

m_prcp2 + ycons)					
S(~NestAge + fm_tag + brood1 + brood2 + brood3)	6	180.58	10.46	0.00	168.50
S(~NestAge + f_tag + m_temp + m_prcp2)	5	180.58	10.47	0.00	170.53
S(~f_tag + m_temp + m_prcp2 + ycons)	5	180.58	10.47	0.00	170.53
S(~brood1 + brood2 + brood3 + m_temp * Time)	7	180.84	10.73	0.00	166.75
S(~Time * m_temp +	7	180.84	10.73	0.00	166.75

brood1 + brood2 + brood3)					
S(~NestAge + y13 + y14 + y15 + y16 + y17 + y18 + y19 + brood1 + brood2 + brood3 + Time * m_temp)	15	180.86	10.74	0.00	150.45
S(~f_tag + m_temp + m_prcp2 + Time + brood1 + brood2 + brood3)	8	181.01	10.90	0.00	164.89
S(~m_tag + m_temp * Time + m_prcp2 + ycons)	7	181.12	11.00	0.00	167.02
S(~m_tag + m_prcp2 + ycons	7	181.12	11.00	0.00	167.02

+ Time * m_temp)					
S(~Time + brood1 + brood2 + brood3)	5	181.15	11.03	0.00	171.09
S(~NestAge + y13 + y14 + y15 + y16 + y17 + y18 + y19 + Time * m_temp + m_prcp2 + brood1 + brood2 + brood3)	16	181.17	11.06	0.00	148.71
S(~fm_tag + m_temp + m_prcp2 + Time + brood1 + brood2 + brood3)	8	181.27	11.15	0.00	165.14
S(~NestAge + f_tag + brood1 +	6	181.41	11.30	0.00	169.34

brood2 + brood3)					
S(~brood1 + brood2 + brood3)	4	181.42	11.30	0.00	173.38
S(~f_tag + Time * m_temp + m_prcp2 + ycons + brood1 + brood2 + brood3)	10	181.50	11.38	0.00	161.31
S(~NestAge + m_temp + m_prcp2)	4	181.55	11.43	0.00	173.52
S(~NestAge + m_tag + Time + brood1 + brood2 + brood3)	7	181.61	11.50	0.00	167.52
S(~m_tag + m_temp +	6	181.78	11.66	0.00	169.71

m_prcp2 + ycons + Time)					
S(~NestAge + y13 + y14 + y15 + y16 + y17 + y18 + y19 + brood1 + brood2 + brood3 + NestAge * Time * m_temp)	18	181.81	11.69	0.00	145.22
S(~NestAge + f_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + Time)	11	181.92	11.81	0.00	159.70
S(~NestAge * Time + f_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19)	12	181.99	11.87	0.00	157.72

S(~m_temp + m_prcp2 + ycons)	4	182.07	11.95	0.00	174.03
S(~m_tag + m_temp + m_prcp2)	4	182.11	12.00	0.00	174.08
S(~fm_tag + Time * m_temp + m_prcp2 + ycons + brood1 + brood2 + brood3)	10	182.26	12.14	0.00	162.07
S(~NestAge + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp + m_prcp2 + Time + brood1 + brood2 + brood3)	15	182.32	12.21	0.00	151.91

S(~Time * m_temp + m_prcp2 + brood1 + brood2 + brood3)	8	182.35	12.23	0.00	166.22
S(~f_tag + m_temp + m_prcp2 + ycons + Time + brood1 + brood2 + brood3)	9	182.37	12.26	0.00	164.22
S(~NestAge + m_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + brood1 + brood2 + brood3 + Time * m_temp)	16	182.57	12.45	0.00	150.10
S(~m_tag + brood1 + brood2)	8	182.79	12.68	0.00	166.67

+ brood3 + Time * m_temp)					
S(~NestAge + brood1 + brood2 + brood3)	5	182.82	12.70	0.00	172.76
S(~fm_tag + m_temp + m_prcp2 + brood1 + brood2 + brood3)	7	182.82	12.70	0.00	168.72
S(~m_temp + m_prcp2 + Time + brood1 + brood2 + brood3)	7	182.82	12.71	0.00	168.73
S(~ycons + brood1 + brood2 + brood3 + Time * m_temp)	8	182.87	12.75	0.00	166.75

S(~ycons + Time + brood1 + brood2 + brood3)	6	182.99	12.88	0.00	170.92
S(~NestAge + m_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + Time * m_temp + m_prcp2 + brood1 + brood2 + brood3)	17	183.01	12.90	0.00	148.49
S(~m_tag + Time + brood1 + brood2 + brood3)	6	183.03	12.91	0.00	170.96
S(~NestAge + fm_tag + y13 + y14 + y15 + y16	10	183.18	13.06	0.00	162.99

+ y17 + y18 + y19)					
S(~fm_tag + m_temp + m_prcp2 + ycons + Time + brood1 + brood2 + brood3)	9	183.28	13.16	0.00	165.12
S(~m_tag + brood1 + brood2 + brood3)	5	183.35	13.24	0.00	173.30
S(~f_tag + m_temp + m_prcp2 + brood1 + brood2 + brood3)	7	183.43	13.31	0.00	169.33
S(~ycons + brood1 + brood2 + brood3)	5	183.43	13.32	0.00	173.38

S(~NestAge + y13 + y14 + y15 + y16 + y17 + y18 + y19 + Time)	10	183.48	13.37	0.00	163.29
S(~NestAge + m_tag + m_temp + m_prcp2)	5	183.57	13.45	0.00	173.52
S(~NestAge * Time + y13 + y14 + y15 + y16 + y17 + y18 + y19)	11	183.65	13.53	0.00	161.42
S(~NestAge + m_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp + m_prcp2 + Time + brood1 +	16	183.72	13.61	0.00	151.26

brood2 + brood3)					
S(~m_tag + m_temp + m_prcp2 + ycons)	5	184.08	13.97	0.00	174.03
S(~Time * m_temp + m_prcp2 + ycons + brood1 + brood2 + brood3)	9	184.29	14.17	0.00	166.13
S(~m_tag + Time * m_temp + m_prcp2 + brood1 + brood2 + brood3)	9	184.32	14.21	0.00	166.17
S(~NestAge + fm_tag + m_temp + m_prcp2 +	8	184.37	14.26	0.00	168.25

brood1 + brood2 + brood3)					
S(~f_tag + m_temp + m_prcp2 + ycons + brood1 + brood2 + brood3)	8	184.70	14.59	0.00	168.58
S(~NestAge + fm_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + Time + brood1 + brood2 + brood3)	14	184.73	14.61	0.00	156.37
S(~NestAge + m_tag + brood1 + brood2 + brood3)	6	184.73	14.62	0.00	172.66
S(~m_temp + m_prcp2 + ycons	8	184.77	14.65	0.00	168.64

+ Time + brood1 + brood2 + brood3)					
S(~m_tag + m_temp + m_prcp2 + Time + brood1 + brood2 + brood3)	8	184.80	14.69	0.00	168.68
S(~fm_tag + m_temp + m_prcp2 + ycons + brood1 + brood2 + brood3)	8	184.81	14.70	0.00	168.69
S(~m_temp + m_prcp2 + brood1 + brood2 + brood3)	6	184.96	14.85	0.00	172.89
S(~NestAge + f_tag + m_temp	8	185.13	15.02	0.00	169.01

+ m_prcp2 + brood1 + brood2 + brood3)					
S(~NestAge + m_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + Time)	11	185.16	15.04	0.00	162.93
S(~NestAge * Time + m_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19)	12	185.19	15.07	0.00	160.92
S(~NestAge + f_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + Time + brood1 + brood2 + brood3)	14	185.57	15.45	0.00	157.21

S(~NestAge + fm_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp + m_prp2)	12	185.99	15.88	0.00	161.72
S(~m_tag + Time * m_temp + m_prp2 + ycons + brood1 + brood2 + brood3)	10	186.24	16.13	0.00	166.06
S(~NestAge + f_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19)	10	186.26	16.15	0.00	166.07
S(~NestAge + m_temp + m_prp2 +	7	186.37	16.26	0.00	172.28

brood1 + brood2 + brood3)					
S(~NestAge + fm_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + brood1 + brood2 + brood3)	13	186.37	16.26	0.00	160.06
S(~m_tag + m_temp + m_prcp2 + ycons + Time + brood1 + brood2 + brood3)	9	186.77	16.65	0.00	168.61
S(~m_temp + m_prcp2 + ycons + brood1 + brood2 + brood3)	7	186.86	16.75	0.00	172.77

S(~m_tag + m_temp + m_prcp2 + brood1 + brood2 + brood3)	7	186.93	16.82	0.00	172.84
S(~NestAge + fm_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp + m_prcp2 + brood1 + brood2 + brood3)	15	187.39	17.28	0.00	156.98
S(~NestAge + y13 + y14 + y15 + y16 + y17 + y18 + y19 + brood1 + brood2 + brood3 + NestAge * Time)	14	187.95	17.83	0.00	159.59
S(~NestAge + y13 + y14 + y15)	9	187.99	17.88	0.00	169.84

+ y16 + y17 + y18 + y19)					
S(~NestAge + y13 + y14 + y15 + y16 + y17 + y18 + y19 + Time + brood1 + brood2 + brood3)	13	188.26	18.14	0.00	161.95
S(~NestAge + m_tag + m_temp + m_prpc2 + brood1 + brood2 + brood3)	8	188.33	18.22	0.00	172.21
S(~NestAge + f_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp + m_prpc2)	12	188.61	18.50	0.00	164.35

S(~m_tag + m_temp + m_prcp2 + ycons + brood1 + brood2 + brood3)	8	188.86	18.75	0.00	172.74
S(~NestAge + m_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19)	10	189.57	19.46	0.00	169.38
S(~NestAge + m_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + Time + brood1 + brood2 + brood3)	14	190.06	19.95	0.00	161.70
S(~NestAge + y13 + y14 + y15 + y16 + y17 + y18 + y19 +	11	190.60	20.49	0.00	168.38

m_temp + m_prp2)					
S(~NestAge + f_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + brood1 + brood2 + brood3)	13	190.71	20.59	0.00	164.40
S(~NestAge + f_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp + m_prp2 + brood1 + brood2 + brood3)	15	191.95	21.84	0.00	161.54
S(~NestAge + m_tag + y13 + y14 + y15 + y16 + y17 + y18 +	12	192.13	22.01	0.00	167.86

y19 + m_temp + m_prcp2)					
S(~NestAge + y13 + y14 + y15 + y16 + y17 + y18 + y19 + brood1 + brood2 + brood3)	12	192.78	22.66	0.00	168.51
S(~NestAge + m_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + brood1 + brood2 + brood3)	13	194.09	23.98	0.00	167.78
S(~NestAge + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp + m_prcp2 +	14	194.49	24.37	0.00	166.13

brood1 + brood2 + brood3)					
S(~NestAge + m_tag + y13 + y14 + y15 + y16 + y17 + y18 + y19 + m_temp + m_prcp2 + brood1 + brood2 + brood3)	15	195.38	25.26	0.00	164.96

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619

620 **Appendix B**

621 **Table B1.** Top models (i.e. models within 2 AICc units of the top model) of nightjar
 622 daily nest survival rates during the **egg stage**, for a set of models including mean
 623 rainfall (m_prcp2), average temperature (m_temp), time (Julian day) and adult female
 624 tag status (f_tag).

Model	nPar	AICc	DeltaAI Cc	Weight	Deviance
S(~f_tag + m_prcp2 + m_temp * Time)	6	66.22	0	0.07	53.99
S(~f_tag + Time)	3	66.75	0.53	0.06	60.689
S(~f_tag)	2	66.94	0.72	0.05	62.909
S(~f_tag + m_temp * Time)	5	67.18	0.95	0.04	57.01
S(~f_tag + m_temp + m_prcp2 + Time)	5	67.54	1.32	0.04	57.37

625

626

627 **Table B2.** Full model averaged estimates (\pm SE) of the effects of mean rainfall, mean
628 temperature, Julian day (Time) and adult female tag status, on daily nest survival rates
629 (DSR) of **egg stage** nightjar nests at Brechfa Forest. Model averaged parameter
630 estimates were derived by weighted averaging across all models within 2 AICc units of
631 the top model (Table B1).

Parameter	Estimate	SE	95% Confidence limits
S((Intercept))	4.48	2.08	0.41 to 8.55
S(f_tag1)	1.56	0.84	-0.08 to 3.19
S(m_prpcp2)	0.24	0.46	-0.66 to 1.14
S(m_temp)	0.78	2.37	-3.87 to 5.43
S(Time)	-0.04	0.05	-0.13 to 0.06
S(m_temp:Time)	-0.01	0.05	-0.1 to 0.09
S(NestAge)	0.07	0.22	-0.36 to 0.51
S(m_temp:NestAge)	0.09	0.27	-0.45 to 0.62
S(NestAge:Time)	0	0	-0.01 to 0.01

S(m_temp:NestAge:Time)	0	0.01	-0.01 to 0.01
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632

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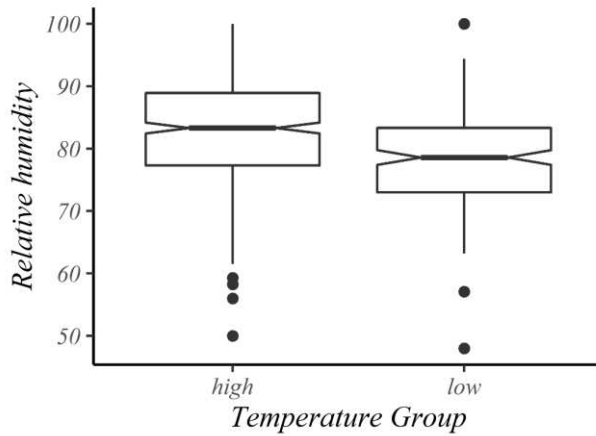
634 **Table B3.** Nest survival rate (DSR¹⁸) estimates for **egg stage** nests at Brechfa Forest
 635 using predicted DSR from model averaged top models for nests initiated on day 20 (16th
 636 June – median nest initiation date).

Tag status	Sample Size	NSR Estimate	95% Confidence limits
Female tagged	27	0.82	0.56 to 1.00
Female untagged	23	0.55	0.37 to 0.72
Adult tagged	33	0.91	0.82 to 0.99
Adult untagged	17	0.87	0.77 to 0.98

637

638 **Appendix C**

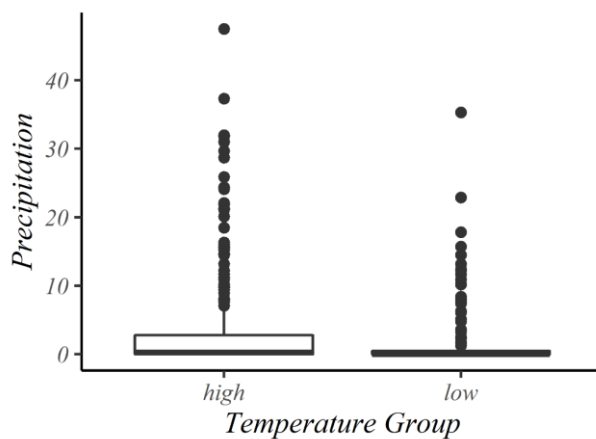
639 **Figure C1:** Boxplot of minimum temperature vs. relative humidity at Brechfa Forest,
640 Carmarthenshire, Wales, 2013–2019 for data split into low temperature (<10°C) and
641 high temperature groups (>10°C).



642

643 **Figure C2:** Boxplot of minimum temperature vs. precipitation (mm) at Brechfa Forest,
644 Carmarthenshire, Wales, 2013–2019 for data split into low temperature (<10°C) and
645 high temperature groups (>10°C).

646



647

648 **Tables**

649 **Table 1.** Summary of nest monitoring results (total no. of nests fledging one chick or
 650 more, and percentage success rates) with a breakdown by tag status of the attending
 651 adults and brood number.

	Total No. nests	No. Success- ful	Overall % Success	% Success 1 st Brood	% Success 2 nd Brood	% Success 3 rd Brood	% Success Unknown
All nests	85	52	61.2	69.5	46.2	50	36.4
Untagged nests	34	21	61.8	70.4	33.3	100.0	0
Nests attended by at least 1 tagged adult	51	31	60.8	68.8	50.0	0.0	50.0
Nests attended by tagged adult male	25	16	64.0	66.7	60.0	NA	60.0
Nests attended by tagged adult female	39	26	66.7	75.0	55.6	0.0	60.0

Nests attended by tagged adult male and female	13	11	84.6	85.7	75.0	NA	100.0
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653 **Table 2.** Summary of number of nests attended tagged parents, broken down by brood
654 status.

	Total	1st brood	2nd brood	3rd brood	unknow n
No. of nests	85	59	13	2	11
No. attended by tagged adult	51	32	10	1	8
No. attended by tagged adult male	25	15	5	0	5
No. attended by tagged adult female	39	24	9	1	5
No. attended by 2 tagged adults	13	7	4	0	2
% attended by tagged adult	60.0	54.2	76.9	50.0	72.7
% attended by tagged adult male	29.4	25.4	38.5	0.0	45.5

% attended by tagged adult female	45.9	40.7	69.2	50.0	45.5
% attended by 2 tagged adults	15.3	11.9	30.8	0.0	18.2

655

656 **Table 3.** Top models (i.e. models within 2 AICc units of the top model) of nightjar daily
657 nest survival rates, for a set of models including mean rainfall (m_prp2), average
658 temperature (m_temp), nest age (NestAge), time (Julian day), adult female tag status
659 (f_tag), year (2013 to 2019) and adult tag status (fm_tag).

Model	nPar	AICc	DeltaAI Cc	Weight	Deviance
S(~NestAge + f_tag + m_temp * Time + m_prp2)	7	170.12	0	0.1227	156.02
S(~NestAge + fm_tag + m_temp * Time + m_prp2)	7	171.27	1.15	0.072	157.17
S(~NestAge + m_temp * Time + m_prp2)	6	171.86	1.75	0.05	159.79

660

661 **Table 4.** Conditional model averaged estimates (\pm SE) of the effects of mean rainfall,
662 mean temperature, nest age, time (days from 28th of May), construction year, adult
663 female tag status and adult male or female tag status, on daily nest survival rates (DSR)
664 of nightjars at Brechfa Forest. Model averaged parameter estimates were derived by

665 weighted averaging across all models within 2 AICc units of the top model (Table 1).

666 Parameters in bold are considered to have an important effect based on 95% CL.

	Estimate	SE	95% Confidence limits
Intercept	5.7157	0.99284	3.770 to 7.662
Nest age	0.07146	0.02756	0.017 to 0.125
Female adult tag status (tagged)	0.76275	0.43062	-0.081 to 1.607
Mean temperature	2.50182	1.08336	0.378 to 4.625
Mean precipitation	0.61952	0.33058	-0.028 to 1.268
Time	-0.07332	0.0233	-0.119 to -0.028
Adult tag status (tagged)	0.80302	0.6496	-0.470 to 2.077
Mean Temperature: Time	-0.03543	0.01924	-0.073 to 0.002

667

668

669 **Table 5.** Full model averaged estimates (\pm SE) of the effects of total rainfall, mean
670 temperature, nest age, time (days from 28th of May), construction year, adult female tag
671 status and adult male or female tag status, on daily nest survival rates (DSR) of nightjars
672 at Brechfa Forest. Model averaged parameter estimates were derived by weighted
673 averaging across all models within 2 AICc units of the top model (Table 1). Parameters
674 in bold are considered to have an important effect based on 95% CL.

	Estimate	SE	95% Confidence limits
Intercept	5.7157	0.99284	3.770 to 7.661
Nest age	0.07146	0.02756	0.017 to 0.126
Female adult tag status (tagged)	0.44476	0.49955	-0.534 to 1.424
Mean temperature	2.50182	1.08336	0.378 to 4.625
Mean precipitation	0.50877	0.38222	-0.240 to 1.258
Time	-0.07332	0.0233	-0.119 to -0.028
Adult tag status (tagged)	0.15784	0.42985	-0.685 to 1.000

Mean Temperature: Time	-0.03543	0.01924	-0.073 to 0.002
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676 **Legends to figures**

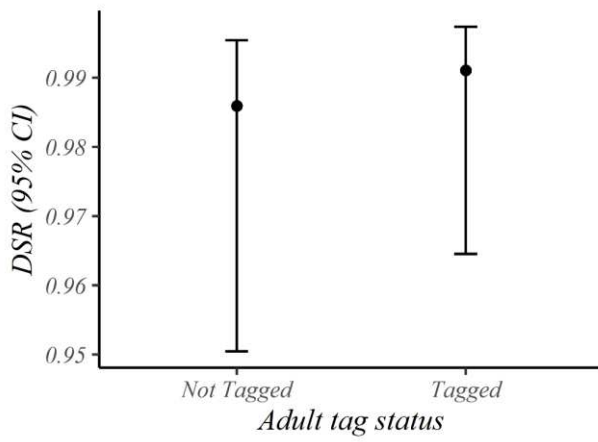
677 **Figure 1:** Relationship between daily survival rate (DSR) and radio tag deployment
678 status of parental adult nightjar at Brechfa Forest, Carmarthenshire, Wales, 2013–2019.
679 Daily survival results are based on 85 nests pooled across 2013–2019. The points
680 represent the estimated mean DSR values, and the bars represent the 95% confidence
681 intervals.

682 **Figure 2:** Relationship between daily survival rate (DSR) and radio tag deployment
683 status of parental female adult nightjar at Brechfa Forest, Carmarthenshire, Wales,
684 2013–2019. Daily survival results are based on 85 nests pooled across 2013–2019. The
685 points represent the estimated mean DSR values, and the bars represent the 95%
686 confidence intervals.

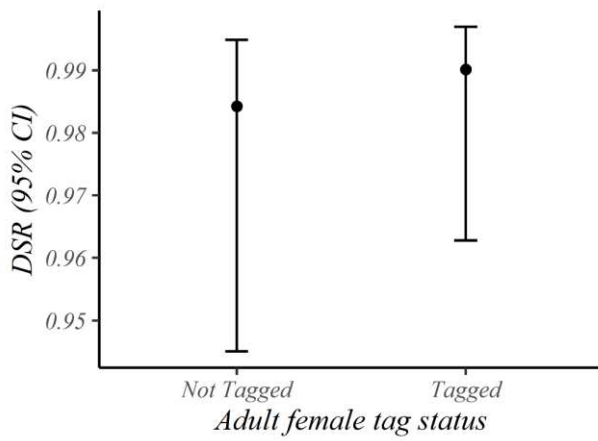
687 **Figure 3:** Model averaged predicted daily nest survival rate in relation to mean
688 temperature during the nightjar nesting period in Brechfa Forest, Carmarthenshire,
689 Wales, 2013-2019. Estimates (lines) and 95% confidence bands (shaded) are shown for
690 day 1 of the season (28th May), day 20 (16th June – median nest initiation date), and day
691 46 (12th July – median hatch date), with other covariates fixed at mean values.

692

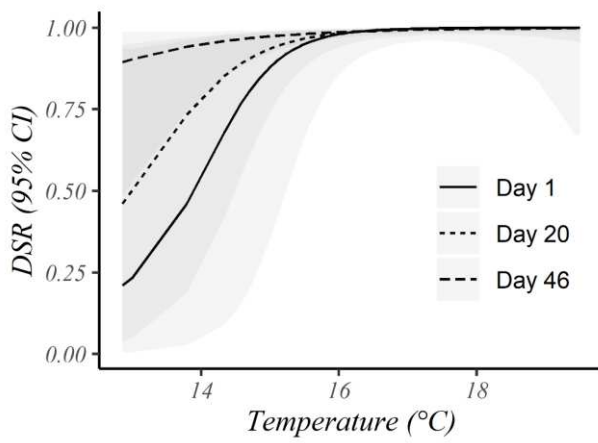
693 **Figures**



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