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# 1 Accuracy in bird predation assessment: Camera traps testing the 2 efficacy of plasticine caterpillars as prey models

## 3 Accuracy in bird predation assessed by camera traps

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11 <sup>¶</sup>Laura Schillé and Nattan Plat share the first co-authorship.

12 <sup>#</sup>Anna Mrazova and Bastien Castagnérol share the last co-authorship.

13

### 14 **Contributions**

15 A.M., L.S., and N.P. developed the original idea. A.M., B.C., L.S., and N.P. developed the  
16 methodology. A.M., B.C., H.J., J.B.R., L.B., L.S., and N.P. conducted data collection. F.R.  
17 implemented the computer code. A.M. and L.S. did the formal analysis and wrote the  
18 original draft, and all co-authors provided critical reviews of the manuscript.

### 19 **Abstract**

20 Sampling methods that are both scientifically rigorous and ethical are cornerstones of any  
21 experimental biological research. Since its introduction 30 years ago, the method of using  
22 plasticine prey to quantify predation risk has become increasingly popular in the field of  
23 biology. However, recent studies have questioned the accuracy of the method, arguing that  
24 inaccuracy in inferring evidence of predator bite marks and the artificiality of models may  
25 bias the results. Yet, bias *per se* might not be a methodological issue as soon as its statistical  
26 distribution in the samples is even, quantifiable, and thus correctable in quantitative

27 analyses. In this study, we focus on avian predation of lepidopteran larvae models, which  
28 represent one of the most widespread predator-prey interactions in various ecosystems  
29 worldwide. We compared bird predation on plasticine caterpillar models to that on dead  
30 caterpillars of similar size and color, using camera traps and observer posterior assessment  
31 to identify biases and quantify actual predation events. Although camera trap analyses  
32 revealed that birds respond similarly to plasticine models and dead caterpillars, suggesting  
33 no advantage in using dead prey for assessing avian predation, the results of posterior  
34 identification of predation marks showed contradictory results, making the interpretation  
35 of the results ambiguous. Observer inconsistencies in detecting predation clues on models  
36 highlight potential biases, with camera trap data showing these clues do not reliably  
37 indicate actual bird predation. Given the uncertainties and shortcomings of technological  
38 character revealed, the development of adequate monitoring methods and further research  
39 is essential to refine the assessment approach and better understand the biases in using  
40 plasticine models.

41 **Keywords:** artificial prey; bird predation; camera trap; ecological methods; fake prey;  
42 plasticine caterpillar models; real caterpillars

## 43 [Introduction](#)

44 The functional role of insectivorous birds in terrestrial ecosystems (1,2) has been the focus  
45 of many studies aimed at understanding the predation patterns, feeding behavior, predator  
46 control of prey populations and evolutionary ecology (3–6). Traditional methodological  
47 approaches to these research topics include direct field observations (7), experimental  
48 manipulation in the laboratory (8,9) or in the field (10), and gut or fecal DNA analyses

49 (11,12). Each of these methods has its own set of limitations regarding standardization,  
50 logistics, and ethical considerations such as not sparing living prey or handling captive  
51 birds. To address these challenges, the use of artificial prey, particularly those made of  
52 plasticine, introduced over 30 years ago by Brodie III (13), has become a valuable tool in  
53 bird predation research (14). The method is primarily appreciated for its ability to preserve  
54 the bite marks of predators, the identification and quantification of which has been used to  
55 infer attacks and predation risk from specific predators.

56 While plasticine caterpillar models are widely employed as simple, standardized prey  
57 models to investigate predation activity in diverse ecosystems (15–17), recent studies have  
58 raised concerns regarding their limitations and potential inaccuracies (14,18–20). The main  
59 concerns relate to the accuracy of inferences of predator identity and activity from the  
60 posterior assessment of putative predation marks on prey models.

61 **Inaccuracy of predator identity** - Observers may struggle to attribute a considerable  
62 portion of attack marks to a specific predator type, e.g., bird, reptile, or arthropod (18,19).  
63 For example, Valdés-Correcher et al. (21) found that up to 24% of predation mark  
64 identifications were inaccurate when assessed by untrained scientists using photos of  
65 attacked plasticine caterpillar models. This was observed in comparison to evaluations  
66 conducted by an expert who had access to the actual plasticine caterpillar models. This  
67 result shows that the identification of predator marks often relies on subjective human  
68 judgment, which can lead to observer bias. This variability is accentuated by the absence of  
69 a standardized training system for observers, thus giving them more certainty in  
70 recognizing such marks (18,22; but see Low et al. (23), for examples of predator-type

71 classified bite mark images), leading to potential discrepancies in interpretations among  
72 researchers.

73 **Inaccuracy in determining real predation events among all identified marks** - Even  
74 though marks were attributed to birds, questions would remain about what one can infer  
75 from them. Incidental contact or non-predatory interactions (e.g., by bird claws, attraction  
76 of non-predatory animals, or curiosity) with the plasticine caterpillar models can result in  
77 marks that are difficult to distinguish from genuine predation attempts, potentially leading  
78 to an overestimation of predation rates (24). The misinterpretation of marks can lead to  
79 distorted results on predation pressure and misleading conclusions about predator-prey  
80 interactions, especially in areas where the attack rate is low (25).

81 Furthermore, the artificial appearance and texture of plasticine may not adequately  
82 simulate the characteristics of real prey, including smell, possibly affecting the behavior of  
83 insectivorous birds and thus the validity of predation assessment (19). The literature  
84 contains several studies that compared the attack rates on plasticine larvae to those of real  
85 larvae, with the latter being quantified based on missing or partially consumed prey items  
86 (19,20,24). As opposed to plasticine caterpillar models, the attack rate on living and dead  
87 prey has shown comparable results (19), thus justifying not using living prey for ethical  
88 reasons (not to glue or pin them alive). By simultaneously studying predation on dead  
89 caterpillars versus plasticine models, it becomes possible to compare the response of  
90 predators to both types of prey within the same experimental design with the use of passive  
91 monitoring methods. This comparative approach makes it possible to test the assumptions  
92 on which the plasticine caterpillar model method is biased and to correct it in relation to

93 observable predation patterns on real dead prey. Quantifying this bias is critical to  
94 determining whether plasticine models can reliably mimic real prey, and thus whether the  
95 data they provide can reflect an accurate depiction of predation pressure.

96 Studies comparing predation on both real caterpillars and plasticine models have shown  
97 discrepancies, revealing that plasticine models may not be a sufficiently accurate method  
98 for assessing predation (19), particularly across large biogeographical ranges (24), varying  
99 thermal regimes (26), different seasons of the bird life cycle (20), and for different taxa  
100 (19). There appears to be a gap in the literature regarding more detailed analyses that  
101 elucidate the origins of the marks found on plasticine models. Moreover, missing plasticine  
102 models are usually excluded from the statistical analyses (16,27). Yet, at least part of those  
103 missing models can be the result of a predation attempt that was not recorded. On the  
104 contrary, studies working with real prey have often assumed that a missing prey was  
105 equivalent to a depredated prey (19,20,24), an assumption that may not always hold true.  
106 Without direct observation, the reasons behind the disappearance of the prey remain  
107 speculative.

108 To address these methodological uncertainties, and following recommendations from  
109 Bateman et al. (18) and Rößler et al. (22), we employed camera traps. As they have been  
110 already used to study bird frugivory (28,29), we suggest their application also to  
111 experimentally record predation on plasticine models (hereafter “models”) paired with  
112 dead caterpillars (hereafter “corpses”) on the experimental trees. We hypothesized that the  
113 integration of camera traps could visually confirm predation attempts, providing a direct  
114 and unbiased record of predator interactions with the prey. This visual evidence could

115 enable the differentiation between actual predation marks and those resulting from  
116 incidental contact or environmental factors (e.g., rubbing by leaves or branches), therefore  
117 increasing the accuracy of predation rate assessment. Ultimately, we believe that the results  
118 of this study will help to refine the plasticine caterpillar model method as a tool for  
119 ecological research, ensuring that it produces scientifically relevant results.

120 We used camera traps to quantify predation events on both prey types and possible sources  
121 of bias in inferences made from plasticine models. We first assessed bias in the detection of  
122 predation clues on plasticine models due to variation among observers (H1). We further  
123 hypothesize that observer detection of predation clues leads to an overestimation of  
124 predation on plasticine models by attributing unrelated or uncertain marks to actual  
125 predation attempts (H2). Taking into account the innate ability of insectivorous birds to  
126 recognize suitable prey and the differences in the surface texture of real vs. plasticine  
127 caterpillars, we hypothesize that there will be evidence of more predation on corpses than  
128 on models, both assessed using camera traps (H3). Finally, we hypothesize that observer  
129 detection of predation would lead to an overestimation of the predation on corpses by  
130 accounting for missing individuals as a predation event, lacking direct evidence for why the  
131 prey disappeared (H4). If we obtain comparable results of the bias between observers and  
132 cameras for both models and corpses, and if the test of H3 provides evidence of more  
133 predation on corpses than on models, we could conclude that the use of corpses with  
134 human post-detection would be a more accurate method than the use of plasticine models  
135 with human post-detection.

## 136 Material and Methods

### 137 Study area

138 We carried out this experiment in a pine and oak forest stand of 5ha near Bordeaux, France  
139 (44°440N, 00°460W). The climate is oceanic, with 12.8°C average temperature and 870mm  
140 annual rainfall. We synchronized the start of the experiment as closely as possible with the  
141 breeding period of local insectivorous birds, specifically, when the chicks were in the nest  
142 and fed by the parents (starting generally mid-April for resident breeders or early  
143 migrants). We choose this timing to quantify bird predation by experienced adults rather  
144 than later exploratory predation attempts by young, inexperienced birds. The main  
145 insectivorous bird species in the study area were Great Tit (*Parus major*), Eurasian Blue Tit  
146 (*Cyanistes caeruleus*), Eurasian Blackcap (*Sylvia Atricapilla*), Common Redstart (*Phoenicurus*  
147 *phoenicurus*), Eurasian Blackbird (*Turdus merula*), Western Bonelli's Warbler (*Phylloscopus*  
148 *bonelli*), Common Chiffchaff (*Phylloscopus collybita*), Short-toed Treecreeper (*Certhia*  
149 *brachydactyla*), Eurasian Nuthatch (*Sitta europaea*), European Robin (*Erithacus rubecula*),  
150 Eurasian Wren (*Troglodytes troglodytes*), and Great Spotted Woodpecker (*Dendrocopos*  
151 *major*) (30).

152 These bird species have home ranges that vary between 0.3 ha for the Blue Tit (31) and 7.9  
153 ha for the Common Chiffchaff (32), the latter value being extreme as compared to most of  
154 the insectivorous species (33,34). It is therefore likely that multiple individuals of the same  
155 insectivorous bird species defended separate territories in the study area. Together with  
156 the fact that we distributed the experiment across the whole forest stand (see below) and  
157 that oak trees host a large density of herbivorous insects (N. Plat, A. Mrazova, and L. Schillé



158 personal observation), we doubt that birds learned to avoid corpses and models during the  
159 experiment.

## 160 Study design

161 First, we haphazardly selected 12 pedunculate oaks (*Quercus robur*, the dominant  
162 broadleaved species of the area) located at least 10m apart from each other. On one branch  
163 accessible from the ground of each of these trees, we glued five plasticine models, and on  
164 another branch as far as possible from the first one, we glued another set of five corpses of  
165 *Operophtera brumata* larvae, previously killed by freezing at -80°C. We use this level of prey  
166 density because (i) the natural density of caterpillars was high at this time of the year, and  
167 (ii) to optimize the use of camera traps by ensuring an adequate number of statistical  
168 replicates. The five caterpillars on each branch were spaced at least 5 cm apart to remain in  
169 the focus of camera traps.

170 We used the lepidopteran species *Operophtera brumata* for experimentation, a widespread  
171 and often abundant oak-defoliating moth. The caterpillars, whether models or corpses,  
172 were directly glued to the branches with two glue drops. We used corpses for ethical  
173 reasons, to avoid gluing living caterpillars.

174 We modeled artificial caterpillars with green plasticine (Staedtler brand, model 8421-5),  
175 forming 1.5 × 0.3 cm cylindrical shapes and mimicking Lepidopteran larvae. They had the  
176 same color as most plasticine models commonly used in studies of predation interactions in  
177 ecology (15–17,23,35) and the same size as *Operophtera brumata* dead larvae used as  
178 corpses.

179 Corpses darken when exposed in the field; after 48 hours, their color differs from that of  
180 live individuals. We cannot exclude that their smell change too. For these reasons, we  
181 exposed fresh models and corpses on a new set of 12 trees every two days. After 16 days,  
182 this procedure resulted in a total of 480 model- and 480 corpse- caterpillars installed on 96  
183 oaks.

#### 184 [Predation analysis](#)

185 We took plasticine models collected in the field to the laboratory in plastic vials. Note that  
186 none of the plasticine models disappeared during the experiment. All models were  
187 examined by three experienced observers who identified marks of attempted predation by  
188 birds using a magnifying glass. The models were considered 'attacked' if they exhibited at  
189 least one attack mark on the plasticine surface. Observers carefully reread the bite mark  
190 guide published by Low et al. (23) beforehand. These observations were used to evaluate  
191 consistency among the observers. In cases of doubt regarding whether a model was  
192 attacked or not, the observers discussed and reached a consensus. Hereafter, we refer to  
193 the presence of marks reported by human observers' consensus as 'predation clues'.

194 Predation clues on corpses were directly examined in the field. A missing corpse or one  
195 with a missing part was considered attacked, as is generally the case in the literature  
196 (19,20,24).

#### 197 [Image analysis](#)

198 Interactions between predators and corpses as well as models were recorded using camera  
199 traps (Brand Ltl Acorn model Ltl-5210M). We installed two camera traps on the trunk of

200 each tree facing the two branches holding models and corpses, respectively. The camera  
201 was positioned about 1m from the caterpillars to make it easier to focus (without blurring)  
202 (Fig 1). The camera traps were active 24 hours a day for the 14 consecutive days of the  
203 experiment. They were set to the highest sensitivity and automatically took bursts of three  
204 photos when the passive infrared (PIR) sensors detected motion with a 0.5s trigger speed.  
205 At each field visit, we changed the SD cards and checked the batteries to replace them if  
206 necessary.

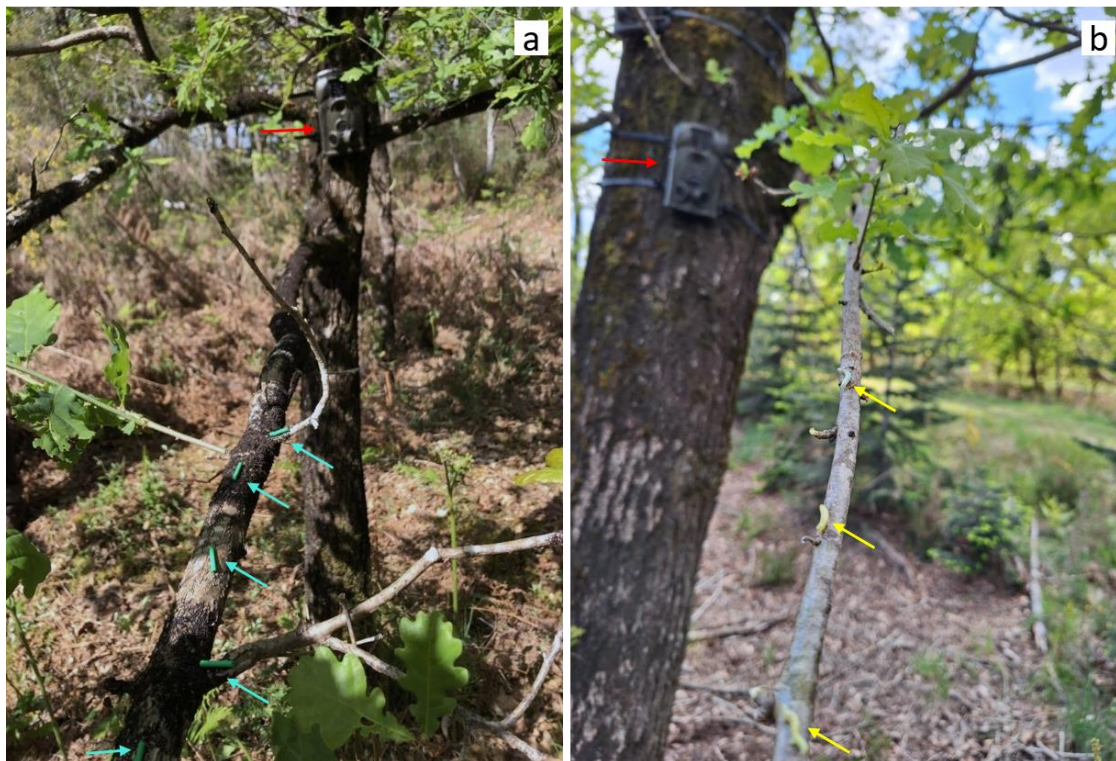
207 We analyzed the images taken by camera traps using the application EcoAssist (36)  
208 supporting the MegaDetector learning model (Machine Learning for Wildlife Image  
209 Classification, (37)). This learning model automatically detects the presence of animals in  
210 images. We used the most conservative detection confidence threshold of 0.01 for the  
211 model in the EcoAssist application, as this threshold previously tested showed a 100%  
212 success rate (i.e., all birds present in the images were detected). Following this detection  
213 process, we carried out a visual examination by an observer of the images. This examination  
214 concerned both corpses and plasticine models.

215 Our camera traps were insufficient to monitor all predation events due to the birds' small  
216 size and stealthy behavior. Therefore, we defined 'evidence of predatory bird presence' at  
217 the branch level as the presence of at least one image showing a foraging bird on the branch  
218 (hereafter 'evidence of bird presence'). These images could show individuals in various  
219 contexts: birds looking at the camera (Fig 2d and 2e), flying over the target branch (Fig 2a),  
220 engaging in foraging activity on the target branch but with natural prey on the bill (Fig 2c

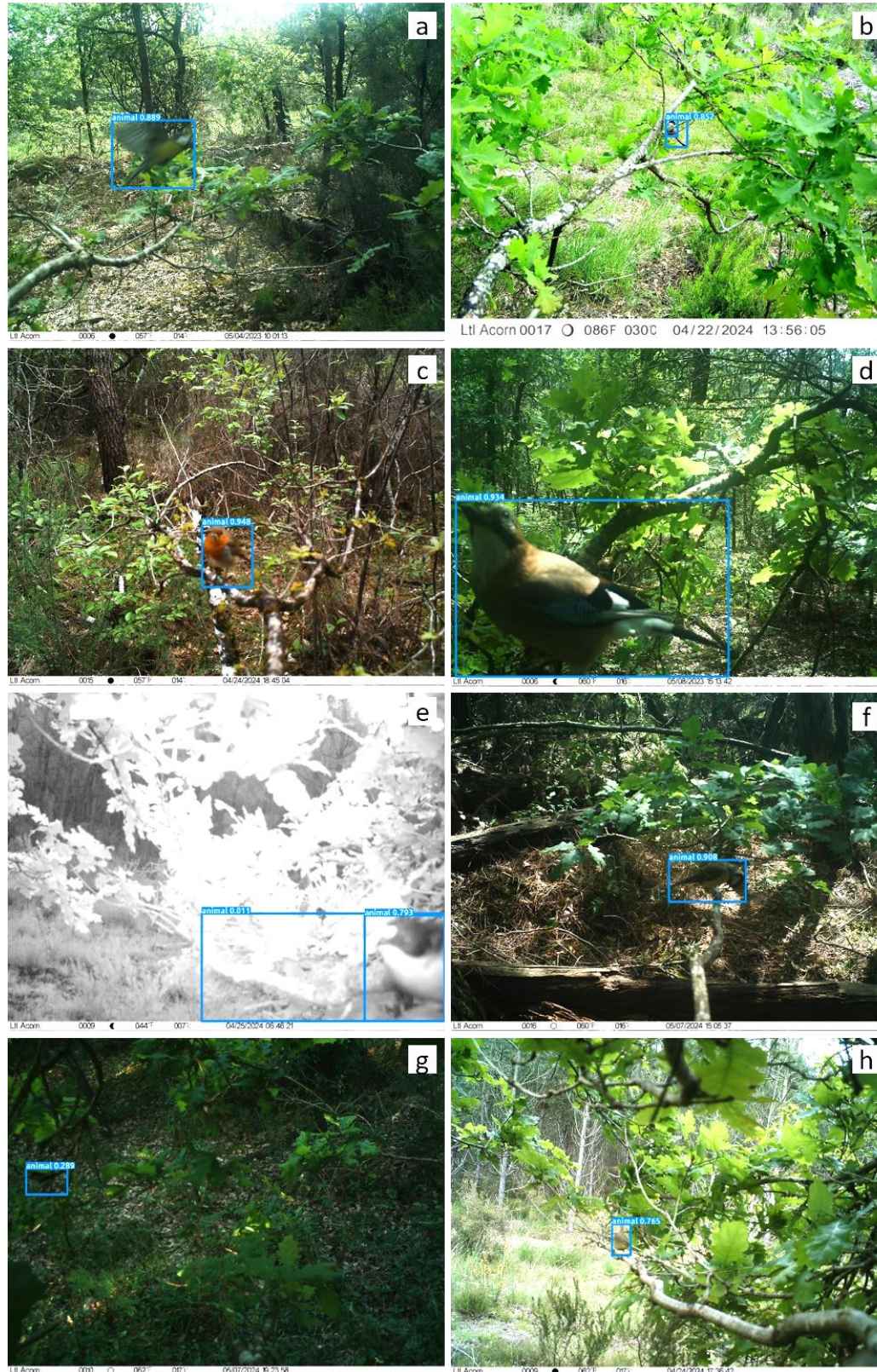
221 and 2e), foraging on experimental prey (Fig 2f and 2h), standing on the experimental  
222 branch (Fig 2b and 2g), or feeding during early morning (Fig 2e).

223 Subsequently, we statistically compared this evidence of bird presence to the predation clue  
224 determined by human observers on the same branch. A branch was categorized as having a  
225 predation clue if at least one of its five caterpillars showed a predation clue.

226 All observed evidence of predator presence, regardless of whether the predator was a bird  
227 or not, was also carefully recorded for further discussion. It should be noted, however, that  
228 arthropod predators were unlikely to be detected by camera traps. We identified all species  
229 associated with the evidence of bird presence.



230  
231 **Fig 1. Photographs of the experimental design in the field.**  
232 *Red arrows point toward the camera traps. Blue and yellow arrows point toward five*  
233 *plasticine models (a) and three corpses (b), respectively.*



234

235

**Fig 2. Camera trap photographs of birds taken in various contexts.**

236 *Birds exhibit different behaviors (perched on a branch, actively foraging, flying, etc., see main*  
237 *text). The blue squares correspond to MegaDetector detections with the associated confidence*  
238 *level. The bird species included are: the Great Tit (Parus major, Figs 2a and 2f), the Long-*  
239 *tailed Tit (Aegithalos caudatus, Figs 2b and 2g), the European Robin (Erithacus rubecula, Fig*  
240 *2c), the Eurasian Jay (Garrulus glandarius, Fig 2d), the European Pied Flycatcher (Ficedula*  
241 *hypoleuca, Fig 2e), and the Common Chiffchaff (Phylloscopus collybita, Fig 2h)*

## 242 **Statistical analysis**

243 All analyses were performed in R (38). Fig 3 summarizes all the hypotheses tested using the  
244 experimental design.

### 245 *Evaluation of the degree of consistency between observers in the posterior detection of bird* 246 *predation clues (H1)*

247 We relied on the intra-class correlation coefficient (ICC) to assess the degree of consistency  
248 between observers in detecting predation clues on plasticine models. The ICC quantifies the  
249 degree of agreement between groups or between observers and is bounded between 0 and  
250 1, where 1 indicates perfect intra-group agreement and 0 indicates no agreement beyond  
251 what would be expected by chance. According to Koo and Li (39), an ICC value below 0.50 is  
252 considered poor, between 0.50 and 0.75 moderate, between 0.75 and 0.90 good, and above  
253 0.90 excellent. We calculated the ICC using the 'icc' function of the *irr* package (40), with a  
254 two-way random effect model because each plasticine model was evaluated by the same set  
255 of three observers.

256 *Comparison between evidence of bird presence assessed by camera traps and predation clues*  
257 *detected by human observers branches with models and corpses (H2 and H4)*

258 We used two generalized linear mixed models (GLMM, *lme4* package; (41)) with a binomial  
259 error distribution to evaluate the bias between observer detection of predation clues and  
260 evidence of bird presence assessed by camera traps on (i) branches with models (H2) and  
261 on (ii) branches with corpses (H4). In both cases, the detection method (predation clues or  
262 evidence of bird presence assessed by a camera) was set as a fixed effect, and tree identity  
263 nested in temporal permutation was considered a random factor. The model equation was:

$$264 \quad Y_{ij} = \beta_0 + \beta_1 \times Detection_{clues,ij} + \gamma_j + \epsilon_{ij}$$

265 where  $Y_{ij}$  is the response variable (one data point per detection method and branch).  $Y_{ij}$   
266 could be zero (no predation clue on any model (H2) or corpse (H4) or no evidence of bird  
267 presence) or one (at least one model (H2) or corpse (H4) with predation clue or evidence of  
268 bird presence).  $\beta_0$  is the model intercept (i.e.,  $Detection_{EvidenceBird,ij}$ ),  $\beta_1$  the coefficient of  
269 the fixed effect of the predation clues detected by the observer (i.e.,  $Detection_{clues,ij}$ ),  $\gamma_j$  the  
270 random intercept for tree identity nested in temporal permutation, and  $\epsilon_{ij}$  the residuals.

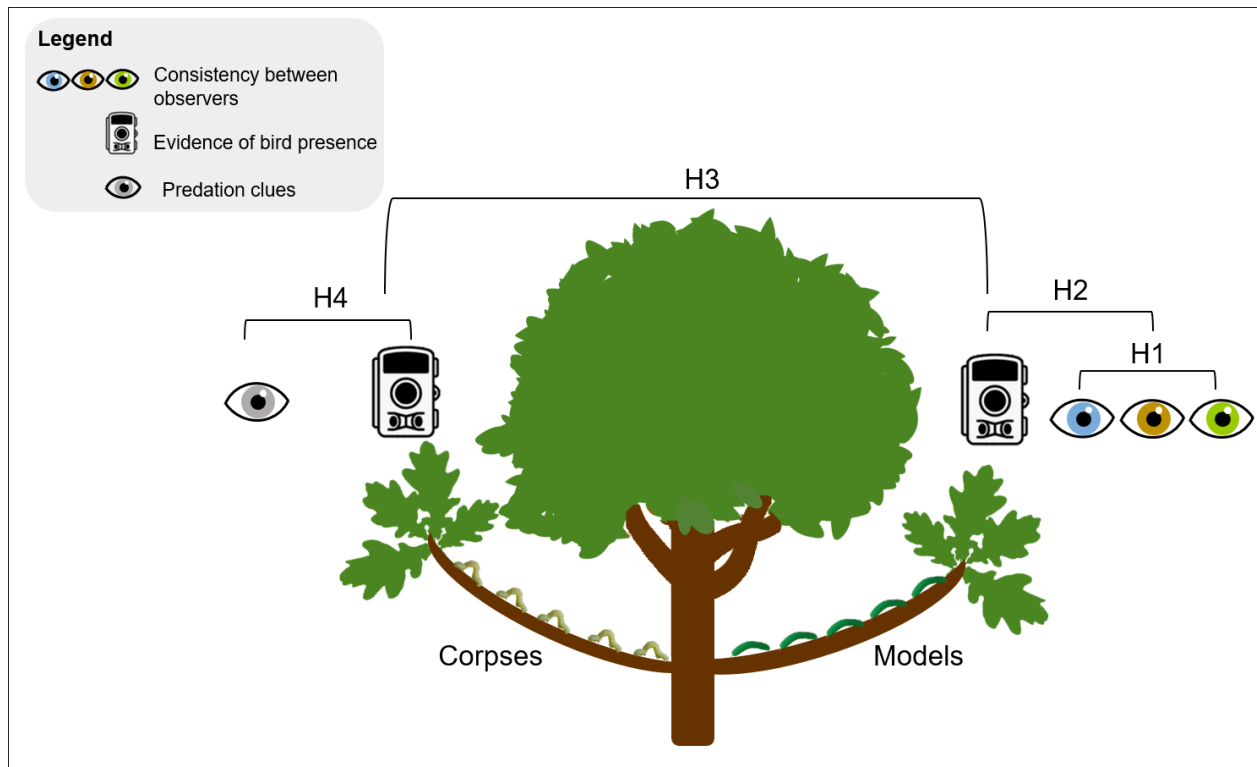
271 *Comparison between the evidence of bird presence on corpses versus models both assessed by*  
272 *camera traps (H3)*

273 We used another GLMM with a binomial distribution to assess the predation bias on models  
274 compared to corpses. Fixed effect was the type of prey (model or corpse) and random  
275 intercepts were tree identity nested in temporal permutation. The model equation was:

$$276 \quad Y_{ij} = \beta_0 + \beta_1 \times PreyType_{Model,ij} + \gamma_j + \epsilon_{ij}$$

277 where  $Y_{ij}$  is the binomial response variable (presence or absence of evidence of bird  
278 presence at the branch level).  $\beta_0$  is the model intercept (i.e.,  $PreyType_{Corpse,ij}$ ),  $\beta_1$  the  
279 coefficient of the fixed effect of the plasticine models (i.e.,  $PreyType_{Model,ij}$ ),  $\gamma_j$  the random  
280 intercept for tree identity nested in temporal permutation, and  $\epsilon_{ij}$  the residuals.

281 For both types of GLMMs, we used the 'nlminbwrap' optimizer, which facilitated model  
282 convergence and provided results comparable to the default optimizer of the *lme4* package.  
283 It should be noted that since the two GLMMs we used are binomial with a *logit* link function,  
284 an inverse transformation of the coefficients must be applied to estimate it as a percentage  
285 of predation.



286  
287 **Fig 3. The experimental design testing the four hypotheses.**

288 *H1: Evaluation of the degree of consistency between observers in the posterior detection of*  
289 *bird predation clues; H2: Comparison between evidence of bird presence assessed by camera*



290 *traps and predation clues detected by human observers branches with models; H3:*  
291 *Comparison between the evidence of bird presence on corpses versus models both assessed by*  
292 *camera traps; H4: Comparison between evidence of bird presence assessed by camera traps*  
293 *and predation clues detected by human observers branches with corpses.*

294

## 295 Results

### 296 Consistency among observers in the detection of bird predation clues (H1)

297 Observer A detected ten predation clues on 480 plasticine models, whereas Observer B and  
298 Observer C detected only three and four predation clues, respectively. At first, the three of  
299 them only agreed on two caterpillars (Fig 4a). The intra-class correlation coefficient (ICC)  
300 score was 0.47 (CI 95%: 0.41 - 0.52) indicating a poor agreement between the three  
301 observers in their assessments of predation clues on the 480 plasticine models ( $F_{(479, 960)} =$   
302  $3.61, P < 0.001$ ). The three observers therefore re-assessed predation clues to reach a  
303 consensus on the attacked vs non-attacked status. The final, consensual status resulting in  
304 seven caterpillars with bird predation clues was used in further analyses.

### 305 Evidence of bird presence on branches with corpses or models assessed by camera traps (H3)

306 We obtained 148,157 images from the cameras. The MegaDetector algorithm detected  
307 animal presence in 37,495 images (using the lowest detection threshold of 0.01  
308 confidence). After visual evaluation, we ultimately retained only 146 photos showing  
309 foraging birds on or around 30 target branches (out of 192). They corresponded to 42 bird  
310 individuals belonging to 10 different species (*Aegithalos caudatus*, *Anthus trivialis*,

311 *Phylloscopus collybita*, *Erithacus rubecula*, *Garrulus glandarius*, *Ficedula hypoleuca*, *Cyanistes*  
312 *caerulus*, *Parus major*, *Fringilla coelebs*, and *Turdus philomelos*). We also detected other  
313 potential predators on certain branches, such as rodents of the genera *Mus* or *Eliomys* and a  
314 Red Squirrel (*Sciurus vulgaris*) (see Figs S1m and z, respectively).

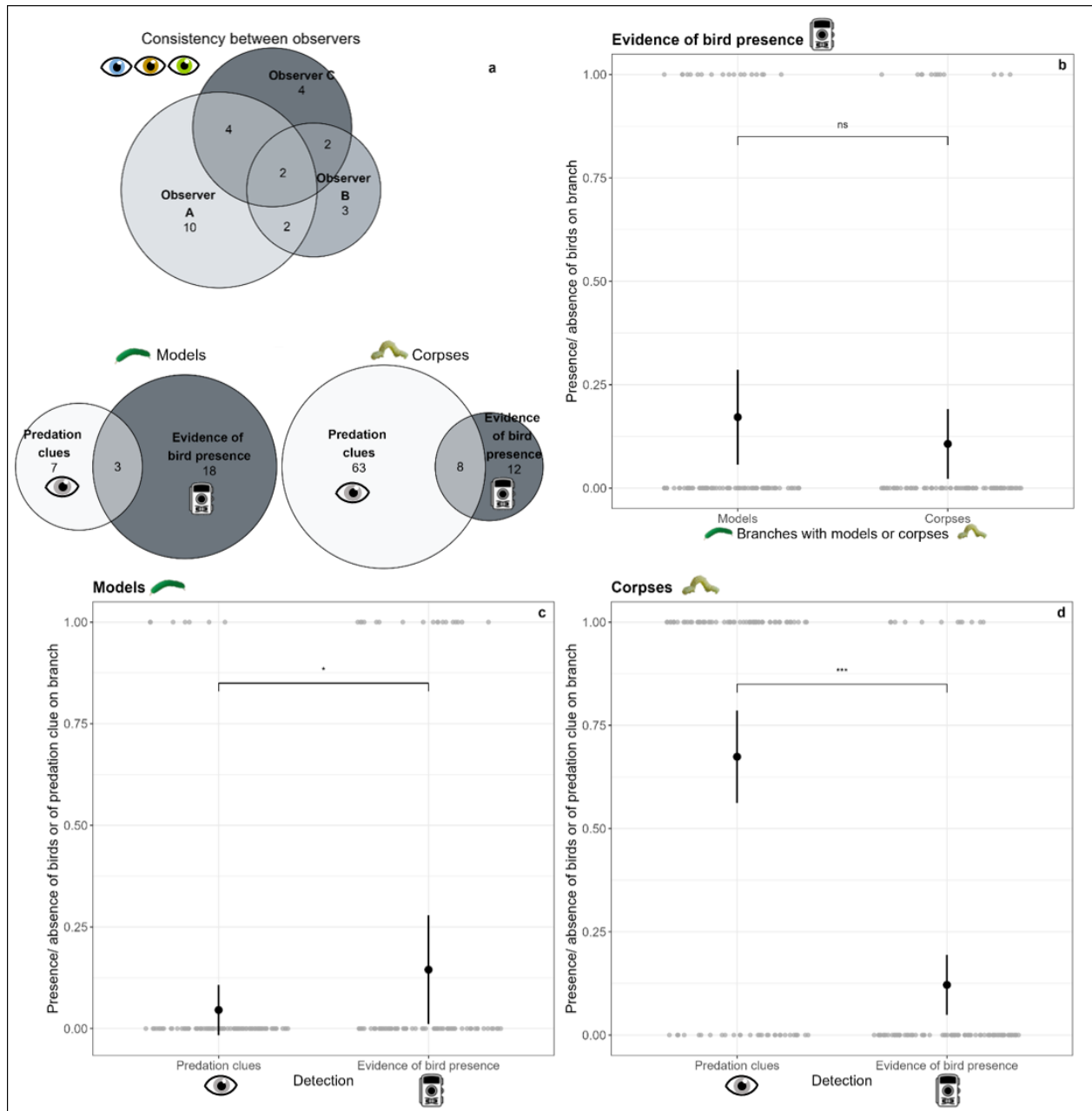
315 Evidence of bird presence, defined as the presence on images of a foraging bird on or flying  
316 toward a branch, did not differ significantly between branches with plasticine models  
317 vs. branches with corpses ( $\beta_{1,Corpse} \pm SE = -0.5 \pm 0.4$ ,  $z = -1.3$ ,  $P = 0.20$ , Fig 4b). A  
318 substantial portion of the variance in bird presence assessment was attributed to random  
319 effect (marginal  $R^2 = 0.019$ , conditional  $R^2 = 0.19$ )

#### 320 Evidence of bird presence vs. predation clues on branches with models (H2) and corpses (H4)

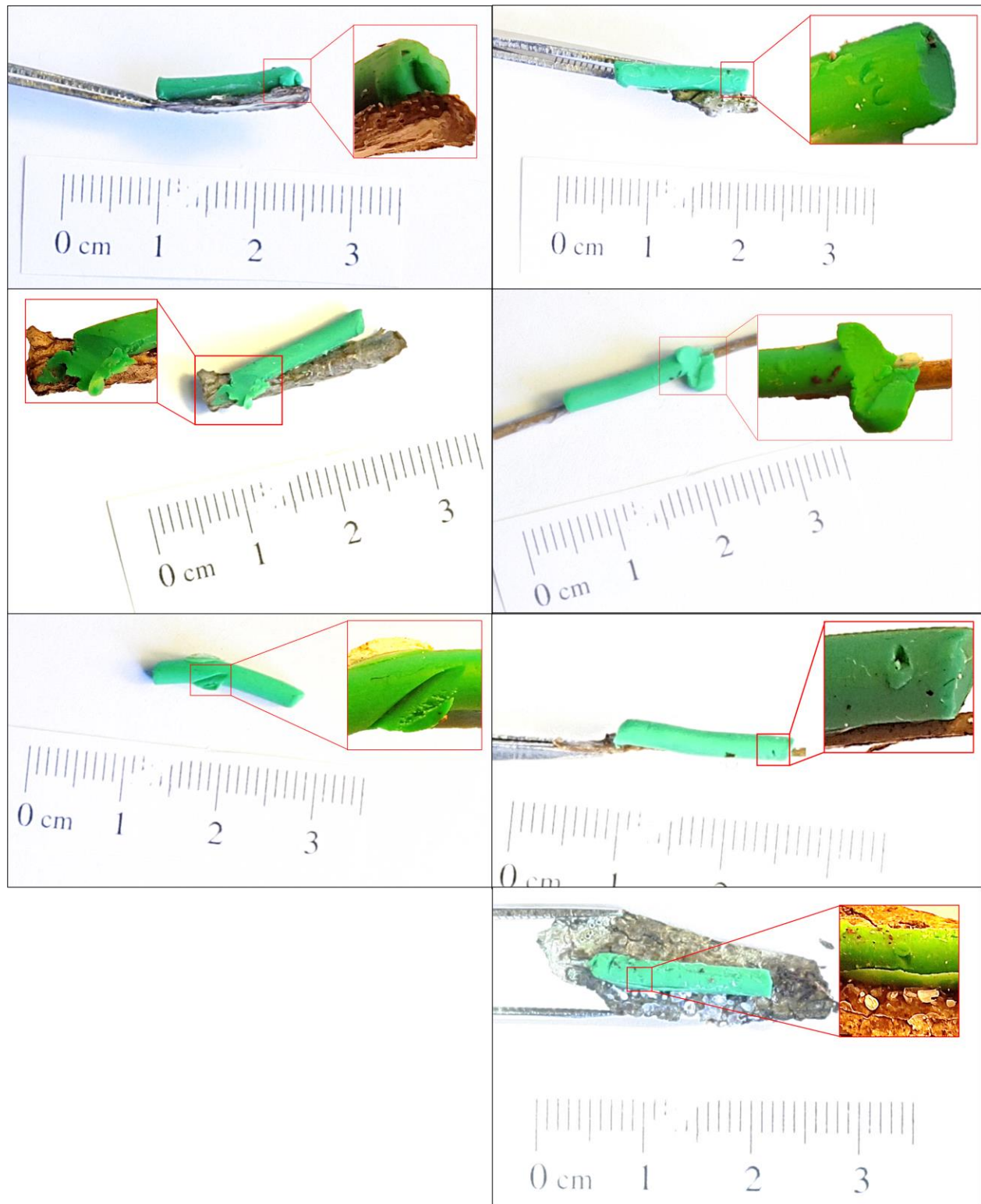
321 We found predation clues on 7 plasticine models (7 branches, Fig 5) and 181 corpses (64  
322 branches). Predation clues on branches with plasticine models were associated with the  
323 presence of a bird on the same branches in the case of three branches. We observed the  
324 presence of birds on 15 branches with no predation clues on models. Predation clues on  
325 models were observed on four branches without the presence of birds being detected by  
326 camera traps (Fig 4a). We therefore detected significantly more evidence of bird presence  
327 than predation clues on branches with plasticine models ( $\beta_{1,Evidence} \pm SE: 1.3 \pm 0.5$ ,  $z = 2.4$ ,  
328  $P < 0.05$ , Fig 4c). A substantial portion of the variance in predation assessment on branches  
329 with plasticine models was attributed to random effect (marginal  $R^2 = 0.08$ , conditional  $R^2 =$   
330 0.34).

331

332 Predation clues on branches with corpses were associated with evidence of bird presence  
333 on the same branches in 8 cases. In contrast, we observed evidence of bird presence  
334 without predation clues on corpses on 4 branches, and predation clues on corpses without  
335 the presence of bird being detected on 56 branches (Fig 4a.). There was therefore  
336 significantly less evidence of bird presence than predation clues on branches with corpses  
337 ( $\beta_{1,Evidence} \pm SE: -2.7 \pm 0.4, z = -6.8, P < 0.001$ , Fig 4d.). The random effect accounted for  
338 only a small fraction of the variance (marginal  $R^2 = 0.35$ , conditional  $R^2 = 0.38$ ).



339  
 340 **Fig 4. Main results of the study.**  
 341 Euler diagram of consistency between the three observers (a, upper panel), and Euler  
 342 diagrams of the number of branches with predation clues and with evidence of bird presence  
 343 for models and corpses (a, lower right and lower left panels, respectively). Results of the  
 344 generalized mixed-effects models with binomial distribution for the three hypotheses tested:  
 345 H2 (c), H3 (b), and H4 (d).



346

347 **Fig 5. Photographs with mark details.**

348 *Seven caterpillars that observers considered to have bird predation clues.*

349

## 350 Discussion

### 351 Lack of consistency in observations of predation clues on plasticine caterpillar models

352 Our study confirms the lack of consistency between observers' evaluation of predation  
353 marks on plasticine models. Despite all trained observers re-reading the attack mark guide  
354 (23), they did not detect the same number of predation clues. Similar results, even among  
355 experienced scientists, were reported by Valdés-Correcher et al. (21) and Castagneyrol et al.  
356 (42), using a more robust experimental design. In our case, the lack of consistency among  
357 observers may have been aggravated by the small size of plasticine models mimicking  
358 *Operophtera brumata* caterpillars (1.5 × 0.3 cm). These models were smaller than the  
359 artificial prey commonly used in the scientific literature (3 cm on average across the five  
360 following studies (16,17,19,23,24)), resulting in a perception of predation marks that  
361 differs from what we typically observed on larger models.

362 To our knowledge, most studies using predation clues on plasticine models rely on a single  
363 observer. Information about whether multiple observers could be involved is also rarely  
364 provided (e.g., when the primary observer consults one or more colleagues for marks on  
365 models that are difficult to assess). Some studies have employed two independent  
366 observers evaluating the models by consensus (43,44), which could be a good method to  
367 avoid observer bias. It could be also advisable to develop an online standardized training  
368 system for identifying bird bill marks on plasticine models, as it is done for insect herbivory  
369 (e.g., ZAX herbivory trainer: <https://zaxherbivorytrainer.com/>(45)). This could  
370 complement the comprehensive guide developed by Low et al. (23) and be tailored to

371 different biomes, considering the substantial variations in predator and prey sizes and  
372 behaviors.

373 [Bird presence assessed by camera traps does not differ between branches with plasticine models](#)  
374 [and corpses](#)

375 The main result of our study revealed that the evidence of bird presence assessed by  
376 camera traps does not significantly differ between experimental branches. Considering that  
377 camera traps caught flying birds and birds foraging under poor light conditions (S1 Figure),  
378 we assume that the cameras do not miss birds when they are present. Such an outcome  
379 would suggest that plasticine models can be used to estimate bird predation, as they offer  
380 the additional advantage of overcoming the ethical issues associated with the use of real  
381 prey, whether dead or alive. This result differs from our findings regarding the number of  
382 predation clues assessed by observers and contradicts other studies that find more bird  
383 attacks on real prey compared to plasticine ones (19,20).

384  
385 Specifically, we observed a ratio of 7 predation clues on plasticine models to 181 on  
386 corpses. Similar to the findings by Zvereva & Kozlov (20), we believe that the corpses were  
387 primarily removed and attacked by arthropods as we found ants crawling around 24  
388 corpses out of 480, but other predators such as spiders or other arthropods could also be  
389 involved. These findings are also in accordance with Nimalrathna et al. (24) who found that  
390 the attack rate by vertebrate predators was lower on dead prey than on live prey and  
391 plasticine models, while invertebrates predated most on dead prey followed by live prey

392 and plasticine models. Considering our and Nimalrathna et al.'s (24) results, we conclude  
393 that our observations of predation on corpses are driven by arthropod consumers.

394 Although tempting to conclude that birds do not distinguish between real and plasticine  
395 caterpillars, and thus claim this method reliable, it must be noted that we cannot rely on the  
396 (i) posterior evaluation of clues on corpses; and (ii) the evidence of bird presence assessed  
397 by camera traps as evidence of predation. Therefore, the evaluation of the plasticine model  
398 method is mostly limited by available technology. To our knowledge, there is currently no  
399 reliable, affordable technique for accurately identifying birds preying on insects. Camera  
400 traps available on the market have motion detection speeds that are too slow for birds or  
401 do not allow for fast sequences of pictures or continuous recording. Cameras that do offer  
402 continuous recording have other limitations in data storage, power supply, and encoding  
403 time. There is thus a need for advanced cameras, that allow us to observe fast behavioral  
404 phenomena of relatively small animals, such as foraging birds. These cameras could be  
405 used in various fields such as trophic interaction ecology, conservation ecology, and  
406 behavioral ecology. Although some initiatives offering prototypes exist (e.g., (46)), the costs  
407 are currently still too high to be affordable for scientific purposes.

408 The most limiting trade-off is between the camera performance and energy consumption.  
409 For scientific research, we need at least 24 hours of endurance, which is currently not  
410 possible for continuous recording. The cameras could therefore operate by capturing a  
411 sequence of pictures at intervals of at least 0.5 seconds continuously to maximize the  
412 chance of capturing the moment of predation (86,400 pictures/day). At the same time, the  
413 batteries must be removable for quick changes in the field. Additionally, the cameras should



414 be affordable, relatively small, light, and waterproof, and finally have programmed a short  
415 encoding time.

416

417 [Predation clues assessed by observers do not correlate with bird presence assessed by camera](#)  
418 [traps](#)

419

420 Predation clues assessed by observers on plasticine models or corpses did not reflect bird  
421 foraging activity as revealed by camera traps. Another study comparing camera traps and  
422 posterior detection to assess predation on artificial snakes also revealed that predatory  
423 birds were underrepresented in the videos triggered after motion detection compared to  
424 the number of predation marks on artificial replicates (47). Moreover, O'Brien & Kinnaird  
425 (48) demonstrated in 2008 that camera traps were more suitable for larger birds such as  
426 pheasants than for functionally insectivorous birds targeted in our study. We acknowledge  
427 that modern camera trap technology has significantly improved since 2008, though, to our  
428 knowledge, however, no recent studies specifically address this in the context of bird  
429 predation.

430 Contrary to our hypothesis, we found more evidence of bird presence than predation clues  
431 on plasticine models suggesting that fake prey underestimates the foraging activity of avian  
432 insectivores. Considering the particularly high density of live prey during this time of year  
433 (L.S., N.P., A.M. pers. observation), an explanation could be that experienced birds prefer  
434 live caterpillars found on the same branch over the models (see also (20)). It is, however,

435 important to consider the low numbers of both observations (clues vs. evidence) (Fig 4c)  
436 implying a weak indicative value.

437 The glue used to attach the prey sometimes caused such small models to harden, potentially  
438 preventing the later detection of predation clues. Finally, we could not exclude curiosity-  
439 driven behaviors from some individuals, notably Eurasian jays, who seemed to gaze intently  
440 at the camera rather than at the available prey. While we anticipated this curiosity  
441 behavior, we expected it to manifest more in predation clues on the models (e.g., such as  
442 claw marks). We carefully re-checked models on which no predation clues were initially  
443 identified, whereas we obtained evidence of birds foraging on the corresponding branches.  
444 The three observers confirmed no predation clue was visible on these models.

445 We observed more predation clues (181) than presence evidence on corpses (12). As  
446 described above, we believe that the effect size is most likely driven by arthropod  
447 consumers. This assumption, however, cannot be currently tested as we are not able to  
448 distinguish between arthropod and bird clues on corpses and at the same time cannot rely  
449 on the evidence of bird presence to be evidence of a genuine predation event. Additionally,  
450 we note that photographs from the camera traps revealed potentially predatory rodents on  
451 one of the branches with corpses.

452 Overall, the results discussed here provide only a limited window to the interpretation of  
453 whether the use of plasticine models should be regarded as a reliable method. Therefore,  
454 we encourage future protocols to explore methods that involve exposing live prey on  
455 branches while non-invasively preventing their escape (e.g., applying glue to branch ends)  
456 in combination with cameras providing unquestionable evidence of bird predation.

## 457 Perspectives

458 Our study still has not answered the most important question, namely whether plasticine  
459 models accurately assess actual predation by birds or not. However, it paves the way for the  
460 use of new technologies, such as passive monitoring methods like video surveillance, to  
461 obtain real evidence of predation. We, therefore, advocate for their development and use,  
462 which will likely refine the widely used plasticine model method in the ecology of trophic  
463 interactions.

464 Taking into account all results and technical difficulties of this study as well as the results of  
465 other studies, we summarized the advantages and disadvantages of each method for  
466 quantifying bird predation, along with future recommendations in Table 1.

467 **Table 1.** Advantages, disadvantages, comments, and recommendations for the three methods of assessing bird predation:  
 468 plasticine models, real prey, and cameras. Note that cameras must be used in combination with one of the other two methods. If a  
 469 cell in the third column spans two rows in the first column labeled 'Methods,' it applies to both methods. Literature references  
 470 supporting our arguments are marked in blue.

Methods	Advantages	Disadvantages	Comments/ recommendations
<b>Plasticine models</b>	<ul style="list-style-type: none"> <li>- Low-cost</li> <li>- Easy method</li> <li>- Standardized</li> <li>- Ethical</li> <li>- Posterior detection possible</li> </ul>	<ul style="list-style-type: none"> <li>- Artificiality: immobile, too bright color resulting in unnatural contrast with branch; non-natural smell; often oversized regarding the size of the species naturally occurring in the habitat</li> <li>- Inconsistency of human detection</li> </ul>	<ul style="list-style-type: none"> <li>- Most models used are too large compared to native European caterpillars ((14); see S2 Figure). Therefore, we recommend adjusting the models' size according to the species likely to be present at study sites.</li> <li>- The vivid green color is not always the most suitable choice for plasticine. We recommend adjusting the color of larvae in a given geography and habitat (e.g., (49)).</li> <li>- We recommend several independent observers (e.g., (43,44)) or an online training system (on the model of (45)) to mitigate the observer detection bias.</li> </ul>
			<ul style="list-style-type: none"> <li>- It is necessary to consider a realistic density of models concerning the actual abundance of prey in the study area at any given time (14).</li> <li>- Consider exposing the prey (models or real caterpillars) according to the natural behavior of the species they represent (e.g., petioles of</li> </ul>

			<p>the leaves, inner space of the rolled leaves, tree trunks, etc.) (e.g., (15,17,27)).</p> <ul style="list-style-type: none"> <li>- Consider the appropriate attachment method regarding the size of the prey, (e.g., the glue may not be the best solution in the case of small prey and could be substituted with pins or double-sided adhesive tape) (e.g., (15,17,27,50)).</li> </ul>
<b>Real prey</b>	<ul style="list-style-type: none"> <li>- Really reflects predation</li> </ul>	<ul style="list-style-type: none"> <li>- Expensive and time-consuming rearing</li> <li>- Unethical</li> </ul>	<ul style="list-style-type: none"> <li>- Use live prey to better reflect predation. Develop protocols to utilize live prey without attachment for ethical reasons while preventing their escape from branches (e.g., (19,20,51)).</li> </ul>
			<ul style="list-style-type: none"> <li>- Combination of real prey and cameras.</li> </ul>
<b>Camera traps</b>	<ul style="list-style-type: none"> <li>- Theoretically allows obtaining evidence of predation by birds (but this study showed that current camera traps do not yet allow this)</li> <li>- Identification of bird species</li> <li>- Detection of other vertebrate predators</li> <li>- Knowing the exact time of predation</li> </ul>	<ul style="list-style-type: none"> <li>- Expensive (52)</li> </ul> <p><u>Currently:</u></p> <ul style="list-style-type: none"> <li>- Passive infrared sensors are not suitable for small birds (48)</li> <li>- Too slow motion detection speeds for photos and even slower for videos</li> <li>- Only a few photos in burst mode after motion detection decrease the chance of capturing the predation event</li> <li>- Too short video times</li> <li>- Non-existing long-term continuous recording</li> <li>- Low data storage</li> <li>- Short-term power supply</li> </ul>	<ul style="list-style-type: none"> <li>- We strongly encourage programmers and electronics to use low-cost microcontrollers coupled with small cameras and high-capacity batteries to obtain real evidence of not only bird predation but generally animal behavior under natural conditions. Such a monitoring method could allow us to conduct reproducible experiments on a large geographic scale, in different habitats, and with multiple target larva species to model an overall bias of the plasticine model method.</li> </ul>

		<ul style="list-style-type: none"><li>- Long encoding time</li><li>- High power supply (52)</li><li>- Need for artificial intelligence to process thousands of photos (46)</li></ul>	
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471

472 **Conclusion**

473 Our study sheds new light on the evaluation of the plasticine model method for  
474 characterizing bird predation. It confirms the existence of an inter-observer consistency  
475 bias in the posterior evaluation of predation marks on these models. It also suggests that  
476 predation clues do not accurately reflect the presence of predatory birds as assessed by  
477 camera traps, neither on the branches bearing the plasticine models nor on those bearing  
478 dead natural caterpillars. As we found no differences in the behavioral responses of birds to  
479 artificial prey compared with dead natural ones, we would conclude that using caterpillar  
480 corpses did not present particular advantages over using plasticine models for assessing  
481 avian predation on folivores. However, taking into account predation clues analyzed by  
482 observers showing contradictory results indicates a non-accurate monitoring approach for  
483 assessing the reliability of this method. Existing technologies do not yet allow this method  
484 to be improved and the use of plasticine to assess bird predation cannot be claimed or  
485 refused using currently available techniques. Our study suggests it is necessary to be able to  
486 evaluate the inherent biases of using plasticine models in field conditions. To this end, we  
487 advocate for the development of more precise monitoring devices and more global  
488 initiatives building upon our study, as soon as such a reliable monitoring method can be  
489 offered.

490

491

492

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500

## 501 Data availability plan

502 The R Markdown format will be used to ensure that the statistical analyses are fully  
503 reproducible, with the code and data made publicly available  
504 (<https://recherche.data.gouv.fr/>) upon acceptance of the study, following the FAIR  
505 principles for scientific data management.

506

## 507 References

508

- 509 1. Díaz-Siefer P, Olmos-Moya N, Fontúrbel FE, Lavandero B, Pozo RA, Celis-Diez JL.  
510 Bird-mediated effects of pest control services on crop productivity: a global synthesis. *J Pest*  
511 *Sci.* mars 2022;95(2):567-76.
- 512 2. Remmel T, Davison J, Tammaru T. Quantifying predation on folivorous insect larvae:  
513 the perspective of life-history evolution. *Biol J Linn Soc.* sept 2011;104(1):1-18.
- 514 3. Ford AT, Goheen JR. Trophic Cascades by Large Carnivores: A Case for Strong  
515 Inference and Mechanism. *Trends Ecol Evol.* déc 2015;30(12):725-35.



- 516 4. Nyffeler M, Şekercioğlu ÇH, Whelan CJ. Insectivorous birds consume an estimated  
517 400–500 million tons of prey annually. *Sci Nat.* août 2018;105(7-8):47.
- 518 5. Sherry TW, Kent CM, Sánchez NV, Şekercioğlu ÇH. Insectivorous birds in the  
519 Neotropics: Ecological radiations, specialization, and coexistence in species-rich  
520 communities. *The Auk.* 24 déc 2020;137(4):ukaa049.
- 521 6. Thiollay JM. Comparative Foraging Success of Insectivorous Birds in Tropical and  
522 Temperate Forests: Ecological Implications. *Oikos.* juill 1988;53(1):17.
- 523 7. Collins CT, Watson A. Field Observations of Bird Predation on Neotropical Moths.  
524 *Biotropica.* mars 1983;15(1):53.
- 525 8. Mäntylä E, Kleier S, Lindstedt C, Kipper S, Hilker M. Insectivorous Birds Are Attracted  
526 by Plant Traits Induced by Insect Egg Deposition. *J Chem Ecol.* déc 2018;44(12):1127-38.
- 527 9. Poloni R, Dhennin M, Mappes J, Joron M, Nokelainen O. Exploring polymorphism in a  
528 palatable prey: predation risk and frequency dependence in relation to distinct levels of  
529 conspicuousness. *Evol Lett.* 11 janv 2024;qrad071.
- 530 10. van Bael SA, Philpott SM, Greenberg R, Bichier P, Barber NA, Mooney KA, et al. Birds  
531 as predators in tropical agroforestry systems. *Ecology.* avr 2008;89(4):928-34.
- 532 11. Michalski M, Nadolski J, Marciniak B, Loga B, Bańbura J. Faecal Analysis as a Method  
533 of Nestling Diet Determination in Insectivorous Birds: A Case Study in Blue Tits *Cyanistes*  
534 *caeruleus* and Great Tits *Parus major*. *Acta Ornithol.* déc 2011;46(2):164-72.
- 535 12. Sam K, Koane B, Jeppy S, Sykorova J, Novotny V. Diet of land birds along an  
536 elevational gradient in Papua New Guinea. *Sci Rep.* 9 mars 2017;7(1):44018.
- 537 13. Brodie III ED. Differential avoidance of coral snake banded patterns by free-ranging  
538 avian predators in Costa Rica. *Evolution.* 1993;47(1):227-35.
- 539 14. Lövei GL, Ferrante M. A review of the sentinel prey method as a way of quantifying  
540 invertebrate predation under field conditions: Measuring predation pressure by sentinel  
541 prey. *Insect Sci.* août 2017;24(4):528-42.
- 542 15. Roslin T, Hardwick B, Novotny V, Petry WK, Andrew NR, Asmus A, et al. Higher  
543 predation risk for insect prey at low latitudes and elevations. *Science.* 19 mai  
544 2017;356(6339):742-4.
- 545 16. Schillé L, Valdés-Correcher E, Archaux F, Bălăcenoiu F, Bjørn MC, Bogdziewicz M, et  
546 al. Decomposing drivers in avian insectivory: Large-scale effects of climate, habitat and bird  
547 diversity. *J Biogeogr.* 4 févr 2024;jbi.14808.
- 548 17. Valdés-Correcher E, Moreira X, Augusto L, Barbaro L, Bouget C, Bouriaud O, et al.  
549 Search for top-down and bottom-up drivers of latitudinal trends in insect herbivory in oak  
550 trees in Europe. *Keith S, éditeur. Glob Ecol Biogeogr.* mars 2021;30(3):651-65.

- 551 18. Bateman PW, Fleming PA, Wolfe AK. A different kind of ecological modelling: the use  
552 of clay model organisms to explore predator-prey interactions in vertebrates. *J Zool. avr*  
553 2017;301(4):251-62.
- 554 19. Rodriguez-Campbell A, Rahn O, Chiuffo MC, Hargreaves AL. Clay larvae do not  
555 accurately measure biogeographic patterns in predation. *J Biogeogr.* 2023;
- 556 20. Zvereva EL, Kozlov MV. Predation risk estimated on live and artificial insect prey  
557 follows different patterns. *Ecology. mars* 2023;104(3):e3943.
- 558 21. Valdés-Correcher E, Mäntylä E, Barbaro L, Damestoy T, Sam K, Castagneyrol B.  
559 Following the track: accuracy and reproducibility of predation assessment on artificial  
560 caterpillars. *Entomol Exp Appl.* 2022;170(10):914-21.
- 561 22. Rößler DC, Pröhl H, Lötters S. The future of clay model studies. *BMC Zool. déc*  
562 2018;3(1):6.
- 563 23. Low PA, Sam K, McArthur C, Posa MRC, Hochuli DF. Determining predator identity  
564 from attack marks left in model caterpillars: guidelines for best practice. *Entomol Exp Appl.*  
565 août 2014;152(2):120-6.
- 566 24. Nimalrathna TS, Solina ID, Mon AM, Pomoim N, Bhadra S, Zvereva EL, et al.  
567 Estimating predation pressure in ecological studies: controlling bias imposed by using  
568 sentinel plasticine prey. *Entomol Exp Appl. janv* 2023;171(1):56-67.
- 569 25. Valdés-Correcher E, van Halder I, Barbaro L, Castagneyrol B, Hampe A. Insect  
570 herbivory and avian insectivory in novel native oak forests: Divergent effects of stand size  
571 and connectivity. *For Ecol Manag. août* 2019;445:146-53.
- 572 26. Muchula K, Xie G, Gurr GM. Ambient temperature affects the utility of plasticine  
573 caterpillar models as a tool to measure activity of predators across latitudinal and  
574 elevational gradients. *Biol Control. févr* 2019;129:12-7.
- 575 27. Mrazova A, Houska Tahadlová M, Řehová V, Sam K. The specificity of induced  
576 chemical defence of two oak species affects differently arthropod herbivores and arthropod  
577 and bird predation. *Arthropod-Plant Interact. avr* 2023;17(2):141-55.
- 578 28. Campos RC, Steiner J, Zillikens A. Bird and mammal frugivores of *Euterpe edulis* at  
579 Santa Catarina island monitored by camera traps. *Stud Neotropical Fauna Environ. août*  
580 2012;47(2):105-10.
- 581 29. Zhu C, Li W, Gregory T, Wang D, Ren P, Zeng D, et al. Arboreal camera trapping: a  
582 reliable tool to monitor plant-frugivore interactions in the trees on large scales. *Remote*  
583 *Sens Ecol Conserv.* 2022;8(1):92-104.
- 584 30. Schille L, Valdés-Correcher E, Archaux F, Bălăcenoiu F, Bjørn MC, Bogdziewicz M, et  
585 al. Data and codes for the article « Decomposing drivers in avian insectivory: large-scale  
586 effects of climate, habitat and bird diversity » [Internet]. *Recherche Data Gouv*; 2024 [cité 2

- 587 févr 2024]. Disponible sur:  
588 <https://entrepot.recherche.data.gouv.fr/citation?persistentId=doi:10.57745/0E0JEA>
- 589 31. Naef-Daenzer B. Radiotracking of great and blue tits: new tools to assess  
590 territoriality, home-range use and resource distribution. 1994;
- 591 32. Lerche-Jørgensen M, Mallord JW, Willemoes M, Orsman CJ, Roberts JT, Skeen RQ, et  
592 al. Spatial behavior and habitat use in widely separated breeding and wintering  
593 distributions across three species of long-distance migrant *Phylloscopus* warblers. *Ecol Evol.*  
594 juin 2019;9(11):6492-500.
- 595 33. Cornell Laboratory of Ornithology. Birds of the World. In: Billerman SM, Keeney BK,  
596 Rodewald PG, Schulenberg TS, éditeurs. Cornell Laboratory of Ornithology, Ithaca, NY, USA  
597 [Internet]. 2022. Disponible sur: <https://birdsoftheworld.org/bow/home>
- 598 34. Naguib M, Titulaer M, Waas JR, Van Oers K, Sprau P, Snijders L. Prior territorial  
599 responses and home range size predict territory defense in radio-tagged great tits. *Behav*  
600 *Ecol Sociobiol.* mars 2022;76(3):35.
- 601 35. Sam K, Koane B, Novotny V. Herbivore damage increases avian and ant predation of  
602 caterpillars on trees along a complete elevational forest gradient in Papua New Guinea.  
603 *Ecography.* 2015;38(3):293-300.
- 604 36. van Lunteren P. EcoAssist: A no-code platform to train and deploy custom YOLOv5  
605 object detection models. *J Open Source Softw.* 2023;8(88):5581.
- 606 37. Beery S, Morris D, Yang S. Efficient Pipeline for Camera Trap Image Review  
607 [Internet]. arXiv; 2019 [cité 16 mars 2024]. Disponible sur:  
608 <http://arxiv.org/abs/1907.06772>
- 609 38. R Core Team. R: A Language and environment for statistical computing. [Internet]. R  
610 Foundation for Statistical Computing, Vienna, Austria; 2021. Disponible sur:  
611 <https://www.r-project.org/>
- 612 39. Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation  
613 Coefficients for Reliability Research. *J Chiropr Med.* juin 2016;15(2):155-63.
- 614 40. Gamer M, Lemon J, Singh IFP. irr: Various Coefficients of Interrater Reliability and  
615 Agreement [Internet]. 2019 [cité 17 mars 2024]. Disponible sur: [https://cran.r-](https://cran.r-project.org/web/packages/irr/index.html)  
616 [project.org/web/packages/irr/index.html](https://cran.r-project.org/web/packages/irr/index.html)
- 617 41. Bates D, Mächler M, Bolker B, Walker S. Fitting Linear Mixed-Effects Models Using  
618 **lme4**. *J Stat Softw.* 2015;67(1):5-8.
- 619 42. Castagneyrol B, Valdés-Correcher E, Bourdin A, Barbaro L, Bouriaud O, Branco M, et  
620 al. Can School Children Support Ecological Research? Lessons from the *Oak Bodyguard*  
621 Citizen Science Project. *Citiz Sci Theory Pract.* 18 mars 2020;5(1):10.

- 622 43. Czarnecki C, Manderino R, Parry D. Reduced avian predation on an ultraviolet-  
623 fluorescing caterpillar model. *Can Entomol.* 2022;154(1):e10.
- 624 44. Franco JC, Branco M, Conde S, Garcia A, Fernandes MR, Lima Santos J, et al. Ecological  
625 Infrastructures May Enhance Lepidopteran Predation in Irrigated Mediterranean  
626 Farmland, Depending on Their Typology and the Predator Guild. *Sustainability.* 25 mars  
627 2022;14(7):3874.
- 628 45. Xirocostas ZA, Debono SA, Slavich E, Moles AT. The ZAX Herbivory Trainer—Free  
629 software for training researchers to visually estimate leaf damage. *Methods Ecol Evol.*  
630 2022;13(3):596-602.
- 631 46. Darras KFA, Balle M, Xu W, Yan Y, Zakka VG, Toledo-Hernández M, et al. Eyes on  
632 nature: Embedded vision cameras for multidisciplinary biodiversity monitoring [Internet].  
633 2023 [cité 19 juin 2024]. Disponible sur:  
634 <http://biorxiv.org/lookup/doi/10.1101/2023.07.26.550656>
- 635 47. Akcali CK, Adán Pérez-Mendoza H, Salazar-Valenzuela D, Kikuchi DW, Guayasamin  
636 JM, Pfennig DW. Evaluating the utility of camera traps in field studies of predation. *PeerJ.* 25  
637 févr 2019;7:e6487.
- 638 48. O'Brien TG, Kinnaird MF. A picture is worth a thousand words: the application of  
639 camera trapping to the study of birds. *Bird Conserv Int.* sept 2008;18(S1):S144-62.
- 640 49. Zvereva EL, Castagnyrol B, Cornelissen T, Forsman A, Hernández-Agüero JA,  
641 Klemola T, et al. Opposite latitudinal patterns for bird and arthropod predation revealed in  
642 experiments with differently colored artificial prey. *Ecol Evol.* déc 2019;9(24):14273-85.
- 643 50. Richards LA, Coley PD. Seasonal and habitat differences affect the impact of food and  
644 predation on herbivores: a comparison between gaps and understory of a tropical forest.  
645 *Oikos.* janv 2007;116(1):31-40.
- 646 51. Sam K, Jorge LR, Koane B, Amick PK, Sivault E. Vertebrates, but not ants, protect  
647 rainforest from herbivorous insects across elevations in Papua New Guinea. *J Biogeogr.* 19  
648 juill 2023;jbi.14686.
- 649 52. Glover-Kapfer P, Soto-Navarro CA, Wearn OR. Camera-trapping version 3.0: current  
650 constraints and future priorities for development. *Remote Sens Ecol Conserv.*  
651 2019;5(3):209-23.

652