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**TITLE**

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**ABSTRACT**

Garden bird feeding constitutes a massive provision of food that can support bird communities, but there is a growing concern it might favour the establishment of exotic species that could be detrimental to others. How bird species compete with novel species for this anthropogenic food resources needs to be assessed.

Here, we investigated competition in wintering bird communities at garden birdfeeders. We evaluated whether – and how much – bird access to resources is hampered by the presence of putative superior competing species, among which the Rose-ringed parakeet, the most abundant introduced species across Europe.

Using the nation-wide citizen science scheme BirdLab, in which volunteers record in real-time bird attendance on a pair of birdfeeders during 5-minute sessions, we tested whether i) cumulative bird presence time and richness at birdfeeders, and ii) species probability of presence at birdfeeders, were influenced by three large species (the Eurasian magpie, the Eurasian collared-dove, and the Rose-ringed parakeet). Additionally, we assessed whether the Rose-ringed parakeet occupied resources significantly more than others.

Presence of the Rose-ringed parakeet or the Eurasian collared-dove similarly reduced community cumulative presence time at birdfeeders, but only the dove reduced community richness. Each of the three large species influenced the presence of at least one of the six smaller species that could be separately modelled, but effects varied in strength and direction. The Rose-ringed parakeet and the Eurasian collared-dove were among the three species monopolising birdfeeders the longest, substantially more than the Eurasian magpie.

Our findings confirm the competitive abilities of the large species studied, but do not suggest that garden bird feeding may alarmingly favour introduced species with detrimental effects on native species. Given the variability of large species' effects on small passerines,

direct and indirect interactions among all species must be examined to fully understand the ecological net effects at stake.

**KEYWORDS:** Citizen Scientists, France, Interference competition, *Pica pica*, *Psittacula krameri*, Serious game, *Streptopelia decaocto*.

## 1. INTRODUCTION

Evidence that anthropogenic resource subsidies to wildlife can have major effects on ecosystems functioning traces back eight centuries ago (Douglas et al., 2004), and this probably occurred to some extent since millennia (Oro et al., 2013). Resources associated to human activities and made available to wildlife, voluntarily or not, can improve the physiological conditions of individuals able to consume these subsidies (Yom-Tov, 2003), increase breeding success (Robb et al., 2008b) and lead to population increases (Galbraith et al., 2015; Oro et al., 2013; Plummer et al., 2019). In turn, in both aquatic and terrestrial realms, food web dynamics can be affected following modification in ecosystem production (Singer and Battin, 2007) or species interactions (Arcos et al., 2001; Cortés-Avizanda et al., 2012; Newsome et al., 2015; Osterback et al., 2015; Rodewald et al., 2011). In recent decades, garden bird feeding strongly increased, involving millions of households worldwide and constituting a theoretical supply of food for millions of birds (Robb et al., 2008a). How this release of a key limiting factor of bird populations (Newton, 1998; Siriwardena et al., 2007), especially during winter, affect bird communities has yet to be fully comprehended.

From a conservation perspective, garden bird feeding may have pros and cons. In urban areas, where bird diversity has been reduced (Chace and Walsh, 2006; Marzluff, 2001) and population declines may be particularly worrying (CBS and Sovon, 2018; SDES and AFB, 2018; Sullivan et al., 2015), garden bird feeding is generally considered beneficial. In

Britain, Plummer and colleagues (2019) reported on a 40-year increase in bird populations of species using feeders, with no change for others, thus resulting in more diverse communities. However, potential detrimental effects are known: nutritionally unbalanced food items can reduce egg production (Plummer et al., 2013), birds' enhanced proximity may increase probability of disease transmission (Galbraith et al., 2017; Lawson et al., 2018), and predation risks could be elevated (Tryjanowski et al., 2015). A major additional concern is the possibility that this provision of readily available food resources could favour the establishment of exotic species. For example, experimental work from the North Island of New Zealand showed that supplementary feeding restructured bird communities to the benefit of exotic species, that were mostly granivorous (Galbraith et al., 2015). In Europe, the introduced Rose-ringed parakeet (*Psittacula krameri*) thrives in cities and has become the most abundant exotic bird species (Pârâu et al., 2016). Garden bird feeding may provide a staple enhancing its survival and its colonisation in temperate climates (Clergeau and Vergnes, 2011).

So far, the Rose-ringed parakeet literature focused on competition for nesting sites [see (White et al., 2019) for a review], whereas this species commonly use birdfeeders (Clergeau and Vergnes, 2011) where it may display the most agonistic behaviours (Le Louarn et al., 2016). Body mass is another important factor determining species' abilities to compete for supplementary feeding at birdfeeders (Francis et al., 2018). To our knowledge, only one study compared potential effects of the Rose-ringed parakeet to a similarly large and dominant native species (the Great spotted woodpecker) at the community-level: presence of a caged bird of either of the latter two species reduced bird visits and feeding, but the Rose-ringed parakeet's effects were stronger (Peck et al., 2014). However, Peck & colleagues' (2014) work was a year-round experiment, and competition outcomes could markedly differ in wintering bird communities exposed to a variety of abiotic and biotic stresses, i.e. under cold

conditions and depleted resources (Pravosudov and Grubb, 1997; Robb et al., 2008b), and when birdfeeders may represent a critical source of food in urban areas. Additionally, there is a need to investigate these questions while controlling for the influence that other large species could have, and with data of bird interactions between free-living individuals.

Our study aims to investigate competition in wintering bird communities at garden birdfeeders, and to evaluate whether an introduced species hampers access to resources. We use data from the Citizen Science scheme BirdLab (Lorrilliere et al., 2018) to carry out a large-scale assessment encompassing different French populations of the Rose-ringed parakeet and various environmental contexts (e.g. urban landscapes, climates), strengthening the representativity of our analysis (Devictor et al., 2010). Coupling a serious game and observations of free-living bird individuals, BirdLab engages volunteers in collecting bird co-occurrences at birdfeeders following a standardised protocol. As bird species differ in their use of birdfeeders and their ability to cope with novelty (Tryjanowski et al., 2016, 2015), we assess responses at both community- and species-level, expecting species may fare differently in competing for resources. Most importantly, we evaluate whether effects of the Rose-ringed parakeet vary from those of two similarly large and potentially aggressive species: the Eurasian magpie (*Pica pica*) and the Eurasian collared-dove (*Streptopelia decaocto*). In Winter, seeds - and potentially other plant materials - constitute the diet of these three large species (Clergeau and Vergnes, 2011; Poling and Hayslette, 2006; Reeb and Boag, 1987; Shiels et al., 2018; Tatner, 1983). While the collared-dove does not spur as much debate as the Rose-ringed parakeet, both arrived in Europe recently (in particular in France, in the early 1950s and 1970s respectively), in contrast with the Eurasian magpie present in Europe by the Middle Pleistocene (Jánossy and Vörös, 1987). Specifically, we tested whether community cumulative presence time and richness at birdfeeders varied between four treatments: control (absence of any large species) and presence of either the Eurasian magpie, the Eurasian



collared-dove, or the Rose-ringed parakeet. To better understand these community-level patterns, we then estimated the time the Rose-ringed parakeet occupied exclusively (i.e., as the only species present) birdfeeders and tested whether it differs from other species' exclusive occupation of birdfeeders. Finally, we investigated whether the presence of either the Eurasian magpie, the Eurasian collared-dove, or the Rose-ringed parakeet influenced the probability of presence of six small species at birdfeeders. Following previous research (Le Louarn et al., 2016; Peck et al., 2014), we hypothesised the Rose-ringed parakeet may hamper birds' access to feeders more than the other two large birds, the Eurasian magpie and the Eurasian collared-dove.

## 2. MATERIALS AND METHODS

### 2.1 DATA COLLECTION

BirdLab (the Feederwatch citizen science project database for France) is a citizen science program in which volunteers follow a standardised protocol to record birds visiting birdfeeders during winter (Lorrilliere et al., 2018). To participate, volunteers set up a pair of identical birdfeeders (hereafter referred to as a '*station*'), distant from 1-2 m from each other. Stations can be private (e.g., in private gardens) or shared (e.g., at a university campus or in a public garden). Each birdfeeder is provided with sunflower seeds, the most preferred food supplement in various human-dominated landscapes (Tryjanowski et al., 2018). Volunteers participate by using a user-friendly application (developed for tablet and smartphone on Android or iOS) in which the two birdfeeders are represented: during a five-minute session, icons of bird species are dragged and dropped to feeders, mimicking movements of the free-living bird individuals visiting the station (Fig. 1). Volunteers thus record in real-time bird arrivals (Fig. 1b), shifts between birdfeeders (Fig. 1c) and departures (Fig. 1d). Each five-minutes session starts when the volunteer drags in the first bird icon on a feeder. The

application includes 27 species commonly seen at birdfeeders in France (Lorrilliere et al., 2018). All 27 species are easily recognized. Nonetheless, the BirdLab application uses timed quizzes to test both bird recognition (made intuitive by relying on icons instead of names) and the speed of dragging-dropping bird icons. Passing the first quiz is mandatory to participate at the ‘beginner’ level (i.e., 14 bird species are available); succeeding in subsequent quizzes (i.e., being able to recognize among more species timely) allows reaching three next levels: ‘Amateur’ (17 species), ‘Confirmed’ (26 species) and ‘Expert’ (27 species). Participation in BirdLab is possible in winter (from November 15<sup>th</sup> to March 31<sup>st</sup>) since 2014.

For each session, the geographical coordinates of the station are obtained using the GPS of the volunteer’s device (tablet or smartphone), along with the date and time of the observation. From each BirdLab session, for each bird, we obtain its species, and when exactly it was present on which birdfeeder. Individuals are not marked and we thus cannot know the actual number of unique individuals per species that were present during a session. For the purpose of the present study, the information we retrieved was, for a given species and session, when exactly it was present and how many simultaneous individuals there were at a station, i.e. combining birdfeeders and allowing to compute a cumulative presence time per species and per session.

## 2.2 DATA SELECTION

We applied several filters relative to data quality and data specificity needed for the biological questions asked in the present paper.

A few sessions included an unlikely high number of species present simultaneously at the station (e.g., reaching 23 out of 27 species), and this most probably indicated that the protocol had not been followed. We determined which stations produced any of the top 1% of sessions in terms of the number of species simultaneously present at birdfeeders, and removed

all sessions from these stations. Remaining sessions had from 0 to 7 species present simultaneously, which is in agreement with our experience of the BirdLab protocol. We removed stations where more than ten volunteer accounts recorded sessions, in order to reduce the variability due to multiple volunteers using a station. Additionally, we kept data from experienced volunteers only by excluding i) the first and second sessions recorded at each station, and ii) sessions recorded at the ‘beginner’ level (see 2.3 for the inclusion of this variable in our statistical models). Sessions carried out in an insufficient level of daylight were removed: we kept those from 30 mn before sunrise to 30 mn after sunset [given the location and date of the sessions, and using the *sunrise* function of the *maptools* package (Bivand and Lewin-Koh, 2019) of R version 3.5.2. (R Core Team, 2018)]. Finally, when two sessions from a station had been recorded less than 30 minutes apart, we randomly kept only one to avoid potential temporal auto-correlation between samplings.

As the Rose-ringed parakeet was added to the BirdLab application on 15<sup>th</sup> November 2017, our dataset spans winters 2017/2018 and 2018/2019. We kept sessions recorded in December, January or February, excluding November and March for which the limited number of sessions precluded their inclusion as levels of the categorical variable ‘month’ in our models. We selected sessions from stations where the Rose-ringed parakeet had been recorded at least once, and further included stations present within 10 km. While maintaining the landscape context (i.e., dominated by urban land-use; Fig. 2b) and the bird communities (i.e., common species found in urban gardens) similar across stations, this allowed us to obtain a dataset fitting our scientific objective: assessing how the presence of large species (European magpie, Eurasian collared-dove, and Rose-ringed parakeet) may affect bird communities at birdfeeders compared to when all large species were absent. To do so, we selected sessions in which none or only one of the three large species studied had been recorded. Importantly, the sessions kept never included other large species present in the

BirdLab program (namely, the Eurasian jay *Garrulus glandarius*, the Carrion crow *Corvus corone*, the Rock dove *Columba livia*, the Common woodpigeon *Columba palumbus*, and the Great spotted woodpecker *Dendrocopos major*), for which the lack of sufficient data prevented their inclusion in the present study. Most volunteers installed birdfeeders of the platform type, and data from stations with birdfeeders of the hanging type were too scarce to be included in the present analysis.

In the end, the total dataset included 818 sessions from 33 stations (Fig. 2), totalling over 68 hours of observations. Among the 27 species considered in the BirdLab program, 21 were included in our final dataset (Table 1).

## 2.3 STATISTICAL ANALYSES

We relied on mixed-effects modelling to investigate how the three large species could affect winter bird communities at the stations included in our dataset. All statistical analyses were performed using R version 3.5.2 (R Core Team, 2018) and mixed-effects models were performed with the *lme4* package (Bates et al., 2015). Below, we first describe the two models investigating bird responses at the community-level (cumulative presence time and richness). Second, we present the model estimating how long each species is the only species present per session. Finally, we describe seven models testing for large species effect on the presence/absence of small species.

### 2.3.1. Community-level

For each session, we computed cumulative presence time and richness of the community (i.e., the 18 small species in Table 1). We used these as the response variables of two separate linear mixed-effects models. To obtain the cumulative presence time, we summed the time for each individual of a species if multiple individuals were present.

Cumulative presence time was log-transformed to meet the assumption of normality of model residuals (see below). Sessions recorded at the same station are not independent of each other, and we thus included ‘Station\_ID’ as a random intercept effect in both models.

The same set of explanatory variables were included in the two models. A large species treatment variable was included (categorical with four levels: ‘Absence’, ‘European magpie present’, ‘Eurasian collared-dove present’, ‘Rose-ringed parakeet present’), with ‘Absence’ of large species being the reference level (i.e., the models tested whether the presence of either of the three large species differed from when all were absent). Other explanatory variables were: winter (categorical variable with two levels: ‘2017/2018’, ‘2018/2019’), month (categorical variable with three levels: ‘December’, ‘January’, ‘February’), volunteer expertise (categorical variable with three levels: ‘Amateur’, ‘Confirmed’, ‘Expert’) and the longitude and latitude of stations (continuous variables) to account for potential spatial auto-correlation in our dataset. We computed variance inflation factors (Zuur et al., 2009) of explanatory variables and found no evidence of collinearity (all VIF values < 2).

We graphically checked that the residuals of each model met the assumptions of homoscedasticity and normality (Faraway, 2016; Zuur et al., 2009). For each model, we graphically confirmed the spatial independence of the residuals by computing a spline correlogram (Zuur et al., 2009) using the *ncf* R package (Bjornstad, 2019). Both models had a sample size of 818 (i.e., number of sessions).

### 2.3.2 Species exclusive occupancy of a station

To better understand how large species may affect others, we ran a linear mixed-effect model estimating how much time per session each species occupied a station as the only species present, and testing whether it differed from the time the Rose-ringed parakeet

occupied a station as the only species present. The recorded times of exclusive occupancy of a station per session were not independent of each other: there were multiple times measured per session (one for each species present), and multiple sessions were recorded per station. We modelled this structuration in the data by including ‘Session\_ID’ nested within ‘Station\_ID’ as a random intercept effect in the model.

The response variable was the species cumulative presence time occupying a station as the only species present per session. A session begins when a bird icon is dragged on a feeder, and the first step for the volunteer is to add the birds that may already be present at either of the two birdfeeders. To account for this design of the protocol that could slightly bias the time a species occupies a station as the only species present, we excluded initial and short sequences of time (i.e., less than 5 seconds within the first 30 seconds) that a species was recorded at the station as the only species present in a session. The resulting cumulative time occupying a station as the only species present per species and session was log-transformed (after adding 1 to each value, to cope with 0’s – occurring for a species present in a session but never occupying a station as the only species present) to meet the assumption of normality of model residuals.

In this model, we included ‘Species’ as an explanatory variable (categorical with 17 levels, corresponding to the 17 species which occurred in at least 20 sessions; Table 1), with ‘Rose-ringed parakeet’ being the reference level (i.e., the model tested whether the cumulative time occupying a station as the only species present per session of a given species differed from the Rose-ringed parakeet value). An additional explanatory variable was the cumulative time of all other species present during the given session, as this could influence the time that a given species occupied the station as the only species present during the session. Other explanatory variables were winter, month, volunteer expertise, and the longitude and latitude

of stations. Variance inflation factors (Zuur et al., 2009) of explanatory variables indicated no worrisome collinearity (all VIF values < 2).

We graphically confirmed that model residuals met the assumptions of homoscedasticity, normality and spatial independence (Faraway, 2016; Zuur et al., 2009). The sample size was 2780 (i.e., number of times species were present in the 818 sessions). We controlled the risk of type I error due to multiple testing in this model (in particular with the 17 levels of the explanatory variable Species) by correcting P values using the false discovery rate control (Verhoeven et al., 2005).

### 2.3.3 Small species probability of presence

We performed separate generalised linear mixed-effects models to test whether the presence of small species differed between sessions with no large species or with one of either the three large species present. Six species had sufficient records in our dataset to be modelled separately (listed as ‘Commonly recorded small species’ in Table 1), and we pooled the remaining 12 species to model them as a group (listed as ‘Other small species’ in Table 1). To account for the lack of independence between sessions recorded at the same station, we included ‘Station\_ID’ as a random intercept effect in the seven models.

In each model, the response variable was binary, corresponding to a species (or the group of other species) being present (1) or absent (0) in a session, and it was therefore modelled with a binomial family and a logit link function.

The same set of explanatory variables were included in the seven models. Again, the large species treatment variable was included, with ‘Absence’ of large species being the reference level. Additionally, we added as an explanatory variable the cumulative presence time of all other species present (except the large one, if present) during the given session, as this could influence the probability of a species to be present in a session. Finally, each model

also included as explanatory variables winter, month, volunteer expertise, and the longitude and latitude of stations. Computing variance inflation factors (Zuur et al., 2009) of explanatory variables, we found no evidence of collinearity (all VIF values  $< 2$ ).

Each model used a subset of the total dataset, tailored to modeling the presence and absence of each species (or the group of 12 species). For each model, we determined in each winter the dates of first and last records of the modelled species and restrained the dataset to sessions within these dates. Then, we only kept sessions from stations where the modelled species had been recorded at least once. In the resulting dataset, we followed Austin & Steyerberg (2017) and checked that there were at least 20 sessions per continuous variable and level of categorical variables. This requirement was met for the six species modelled separately, although one level of a categorical variable had to be dropped in the House sparrow model (effect of the Rose-ringed parakeet presence could not be tested). We had to group the 12 remaining species to verify this condition, unmet when kept separated. The final sample sizes for these seven models are provided in Figure 5. In each model, we checked there was no over/under-dispersion and no zero-inflation using the R package *DHARMa* (Hartig, 2019); we also followed Faraway (2016) and graphically checked model residuals using the R package *arm* (Gelman and Su, 2018). The assumption of spatial independence of model residuals was graphically confirmed.

### 3. RESULTS

In presenting the results of our models, statistically significant relationships were considered for p-values lower than 0.05.



### 3.1 COMMUNITY-LEVEL

The cumulative presence time of small species was significantly lower in the presence of either the Eurasian collared-dove (94.4 s, i.e. -33%) or the Rose-ringed parakeet (80.5 s, i.e. -43%) in comparison with sessions free of large species (Fig. 3a, Table 2). Presence of the Eurasian magpie was not significantly associated with a change in the cumulative presence time of small species. On average, volunteers of the highest level of expertise ('Expert') recorded significantly longer cumulative presence time of small species per session than 'Amateur' volunteers (Table 2).

Compared to sessions without large species, we only detected a significant difference in small species richness in the presence of the Eurasian collared-dove (Fig. 3b, Table 2), which was associated to 0.46 fewer species in average (i.e. -13%). In contrast, the presence of the Eurasian magpie or the Rose-ringed parakeet were not significantly associated with changes in the richness of small species in a session. On average per session, both 'Confirmed' and 'Expert' volunteers recorded significantly higher small species richness than 'Amateur' volunteers (Table 2).

### 3.2 SPECIES EXCLUSIVE OCCUPANCY OF A STATION

Over the 41 sessions in which the Rose-ringed parakeet was recorded, it occupied a station as the only species present during 26.3 s per session on average (Fig. 4). Out of the 16 other species for which such an estimation could be computed, only the European goldfinch and the Eurasian collared-dove tended to occupy a station as the only species present for a longer period of time, although the difference with the Rose-ringed parakeet was not significant (Table 3). The Eurasian magpie (with 5.5 s) was among the 11 species that occupied stations as the only species present for a significantly shorter duration than the Rose-ringed parakeet. No significant effect of volunteer expertise was detected (Table 3).

### 3.3 SMALL SPECIES PROBABILITY OF PRESENCE

Among the six small species whose probability of presence could be modelled separately, the presence of four species was significantly associated with the presence of at least one large species (Fig. 5, Table 4). Presence of the Rose-ringed parakeet was significantly associated with a substantial reduction in the probability of presence of the European robin. Presence of the Eurasian magpie and the Eurasian collared-dove were associated with significantly reduced probability of presence of the Eurasian blue tit, and the Eurasian collared-dove was also associated with a decreased probability of presence of the Great tit. Interestingly, there were some positive associations between the presence of a large species and the probability of presence of some small species, although this pattern was only significant between the Eurasian collared-dove and the House sparrow (Fig. 5, Table 4).

As a group, the probability of presence of the 12 small species that could not be modelled separately was not significantly associated with the presence of any of the three large species.

Compared to sessions from ‘Amateur’ volunteers, sessions from ‘Confirmed’ volunteers were more likely to include the European robin and sessions from ‘Expert’ volunteers were more likely to include the Great tit (Table 4). Additionally, the probability of presence of the group of 12 small species (‘Other small species’) was significantly higher in sessions from both ‘Confirmed’ and ‘Expert’ volunteers.

## 4. DISCUSSION

Within urban environments where garden bird feeding in winter represents a novel and increasing anthropogenic food supplement, we examined the competition within bird communities and evaluated the competitive roles of large and/or novel species. Using data

from a nation-wide and innovative citizen science scheme recording bird attendance and co-occurrences at birdfeeders, we found that the introduced Rose-ringed parakeet was among the most preemptive competitor species (i.e., occupying a pair of birdfeeders exclusively) and that this led to reduced community-level presence time at birdfeeders. However, delving into co-occurrences of species, the probability of presence of only one species (the European robin) out of six was significantly reduced in the presence of the Rose-ringed parakeet. Most importantly, we compared the effects of the Rose-ringed parakeet with two other large species and our findings suggest that while the competition for food resources differ from the other two large species at the species-level, it does not have a larger effect at the community-level. Our findings, with complementary work on the Rose-ringed parakeet's competition for nesting sites (Strubbe et al., 2010), are in agreement with a theoretical and empirical body of knowledge suggesting that competition from introduced to native species is not expected to have large effects (Davis, 2003), in birds in particular (Martin-Albarracin et al., 2015).

We are aware of only two studies that assessed competition for food resources from the Rose-ringed parakeet, and the analysis of our large dataset (68.2 hours of observations) of free-living birds at birdfeeders complement and expand our previous understanding of the Rose-ringed parakeet's potential effect. Our results at the community-level empirically confirm the experimental work of Peck et al. (2014) who had found that a caged Rose-ringed parakeet or its calls reduced feeding rate. From four hours of video recordings of birds at birdfeeders, Le Louarn et al. (2016) suggested that the Rose-ringed parakeet displayed the most antagonistic behaviours among eight species, including the Eurasian collared-dove. However, we found that the two species similarly reduced community cumulative presence time and that only the dove was associated with lower community richness. This discrepancy highlights that predicting community-level responses from behaviours between individual pairs is not straightforward. Indeed, out of six small species, we found that three displayed a

probability of presence at birdfeeders negatively associated with one or more large species, and that one species (the House sparrow) was positively associated to one of the large species (Fig. 5). These various patterns of co-occurrences at feeding sites may result from direct and indirect effects of competitive interactions within bird communities (Wootton, 1994), that may buffer detrimental effects of antagonistic encounters. Further examination of co-occurrences among and between small and large species at birdfeeders will be critical to untangle the net ecological effects of any species in the community.

In common with previous work studying bird competition in urban areas (Le Louarn et al., 2016; Peck et al., 2014; Tryjanowski et al., 2018), the extent with which relying on birdfeeders as food resources may represent competition for natural resources is uncertain. Food resources for wintering birds are arguably less spatially aggregated in natural or agricultural settings compared to seeds on birdfeeders, and preemptive competition for wild resources may thus be less important than we observed with feeders. However, given the prominence of garden bird feeding in urban areas (Robb et al., 2008a) and how these anthropogenic food subsidies affect the temporal dynamics of bird communities (Plummer et al., 2019), competition at birdfeeders may represent a substantial part of competition for food resources in urban landscapes, especially in winter. Additionally, the BirdLab protocol is to use sunflower seeds, but birds have dietary preferences (Francis et al., 2018; Poling and Hayslette, 2006; Tryjanowski et al., 2018) that can influence investment in foraging and/or competition. In the future, the BirdLab protocol could thus open up to different food items for volunteers to use at birdfeeders, in order to investigate how resource identity affects competition within bird communities. This perspective could also provide insights into why, out of the three large species, only the Eurasian magpie stayed short periods on birdfeeders (Table 1), whereas all three large species rely on seeds and other plant materials during winter (Clergeau and Vergnes, 2011; Poling and Hayslette, 2006; Tatner, 1983).

Considerable research efforts are devoted to understanding how exotic species may affect native species (Godet and Devictor, 2018; Simberloff et al., 2013). However, evaluating the effects of introduced species may be difficult when lacking a comparison with functionally equivalent native species. In this paper, we included not only a native equivalent (the Eurasian magpie) of the Rose-ringed parakeet but also a neonative species [the Eurasian collared-dove, which naturally colonised the country; following the definition of Essl and colleagues (2019)]. Because the neonative species has now widely spread in France since its colonisation about two decades before the introduced Rose-ringed parakeet, the native bird communities could be more habituated to its competitive pressure than that of the Rose-ringed parakeet. However, interestingly, our results at both community- and species-level suggest the neonative species to be a greater competitor for these anthropogenic food subsidies than the Rose-ringed parakeet. Additionally, the large native and exotic species did not affect the same species at birdfeeders. Therefore, to better understand, predict and manage the effects that any species - regardless its origin - may have on ecosystems, we emphasise that ecologists should focus on species traits (Davis et al., 2011; Fournier et al., 2019), for example, body mass, trophic and nesting preferences, or phenology (Orchan et al., 2013).

Relying on citizen science – “*the involvement of volunteers in scientific research*” (Dickinson et al., 2010) – was essential to this study. Citizen science has proven highly valuable to advance research in a wide range of disciplines (Cooper et al., 2014; McKinley et al., 2017; Theobald et al., 2015). While data quality or sampling bias may raise analytical challenges, appropriate project design (e.g. standardised protocol, methods to engage volunteers), post-collection filtering and/or validation of data, and statistical solutions can overcome most existing limitations (Bird et al., 2014; Follett and Strežov, 2015; Serret et al., 2019). We here acknowledge that a limitation of the BirdLab dataset is the impossibility to validate observations *a posteriori* and to rule out identification errors. However, we argue that

our results can be trusted for three reasons. First, we only kept data from experienced volunteers and further adjusted for volunteers' expertise in all statistical models. Second, the BirdLab protocol is limited to 27 very common and easily recognizable species, and this is particularly true of the three large species (especially the Rose-ringed parakeet) and the six small passerines which were analyzed separately (Fig. 5). Last but not least, identification errors from any volunteers should be largely independent of the variable of interest in the present analysis, i.e. presence or absence of a large species, and therefore have very little qualitative impact on our findings. The fact that we detected significant effects of volunteer' expertise in several of our models highlights that accounting for volunteer experience when analysing citizen science data may be essential to ensure that effects of ecological variables of interest are as unbiased as possible.

Within only two years, the BirdLab scheme gathered a sufficiently large dataset of standardised observations to assess competition from the Rose-ringed parakeet, still a spatially restricted species in France despite being the most abundant exotic bird in Europe (Pârau et al., 2016). Effects from the two novel species (Rose-ringed parakeet and Eurasian collared-dove) on the attendance at birdfeeders would be better estimated if we had data prior arrivals. These data are lacking so far; however, with expanding Rose-ringed parakeet populations in France (Clergeau et al., 2015), the BirdLab scheme will be in a unique position to determine how an exotic bird integrate and potentially modify community interactions in winter. Documenting such community interactions changes at birdfeeders may be critical to understanding the mechanisms behind temporal species abundance trends revealed by long-term monitoring, emphasizing the interest of coupling complementary citizen science scheme (Lorrilliere et al., 2018). For example, this could help disentangle effects and causes of concomitant native and exotic populations temporal trends (Colléony and Shwartz, 2020). This illustrates how valuable citizen science can be to advance our knowledge of biological

invasions (Roy et al., 2018), beyond other ecological goals and educational benefits (Deguines et al., 2020, 2018; McKinley et al., 2017).

## 5. CONCLUSIONS

Garden bird feeding is an increasingly popular activity that provides food supplement to birds and can restructure entire communities (Galbraith et al., 2015; Plummer et al., 2019). In this study, we sought to examine how wintering birds compete for this novel resource and cope with a large and putatively competitive exotic species. We directly compared the introduced Rose-ringed parakeet with two similarly large and potentially aggressive (neo)native species and, thanks to an innovative semi-experimental citizen science scheme, investigated this issue with national-scale data of free-living birds attending birdfeeders. At the community-level, we found that the Rose-ringed parakeet and the Eurasian collared-dove reduced community cumulative presence time at birdfeeders. However, only the dove also reduced community richness. This is in line with our findings that the Rose-ringed parakeet and the Eurasian collared-dove were the strongest preemptive competitor (i.e., monopolising birdfeeders), in contrast with the Eurasian magpie. Interestingly, at the species-level, responses to the three large species varied in strength and direction (positive or negative associations), calling for further considerations of interspecific direct and indirect interactions. For example, antagonistic encounters among large species, native or introduced, could have ripple effects on smaller passerines and key ecosystem functions (e.g. seed dispersion, insect predation). This, and the opportunity in future years to monitor how the most abundant exotic bird in Europe integrate local communities, constitute critical fundamental and applied research perspectives which the BirdLab citizen science program should be able to tackle thanks to the involvement of volunteers.

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## AUTHORS' CONTRIBUTIONS

ND, RL, FC and CBG conceptualized the ideas and designed the methodology; ND analysed the data, designed the figures, and led the writing of the manuscript; RL curated the data; AD, RL, FC and CBG managed the BirdLab scheme. All authors contributed critically to the drafts and gave final approval for publication.

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**Table 1. List of the 21 species included in the study.** ‘Large species’, ‘Commonly recorded small species’ (species which response to large species presence could be separately estimated, see Methods and Fig. 5) and ‘Other small species’ (species that were pooled before estimating an overall response to large species presence, see Methods and Fig. 5) are ordered by decreasing number of sessions they were recorded in. The mean body mass was retrieved from Demongin and colleagues (2020).

	Number of sessions recorded in	Number of stations recorded at	Median presence time (s)	Mean body mass (g)
<b>Large species</b>				
Eurasian Collared-Dove ( <i>Streptopelia decaocto</i> )	92	23	99.7	205.0
Eurasian Magpie ( <i>Pica pica</i> )	42	7	7.3	230.5
Rose-ringed Parakeet ( <i>Psittacula krameri</i> )	41	17	161.6	148.0
<b>Commonly recorded small species</b>				
Eurasian Blue Tit ( <i>Cyanistes caeruleus</i> )	597	28	22.8	11.3
Great Tit ( <i>Parus major</i> )	539	33	17.8	18.0
Common Chaffinch ( <i>Fringilla coelebs</i> )	370	22	105.2	23.3
House Sparrow ( <i>Passer domesticus</i> )	276	14	78.5	28.9
European Robin ( <i>Erithacus rubecula</i> )	202	19	26.1	19.0
European Greenfinch ( <i>Carduelis chloris</i> )	184	15	133.6	29.8
<b>Other small species</b>				
	372	27	34.75	
Dunnock ( <i>Prunella modularis</i> )	115	6	29.0	20.0
European Goldfinch ( <i>Carduelis carduelis</i> )	67	13	286.6	16.5
Coal Tit ( <i>Periparus ater</i> )	59	8	8.0	10.3
Crested Tit ( <i>Lophophanes cristatus</i> )	51	12	7.6	11.5
Marsh Tit ( <i>Poecile palustris</i> )	40	7	10.5	11.5
Eurasian Nuthatch ( <i>Sitta europaea</i> )	38	7	16.7	22.5
Eurasian Blackbird ( <i>Turdus merula</i> )	36	6	24.1	102.5
Hawfinch ( <i>Coccothraustes coccothraustes</i> )	31	8	143.6	59.0
Eurasian Tree Sparrow ( <i>Passer montanus</i> )	17	4	20.6	21.5
Eurasian Siskin ( <i>Carduelis spinus</i> )	7	4	34.2	13.5
Brambling ( <i>Fringilla montifringilla</i> )	4	2	8.9	25.7
European Starling ( <i>Sturnus vulgaris</i> )	4	4	44.2	83.5

**Table 2. Results of the community-level mixed effects models.** Predictors' estimates are shown for the linear mixed-effects models (Cumulative presence time, Richness), along with their associated standard errors (SE), and *P*-values (*P*). 'EM', 'ECD' and 'RRP' respectively stand for the 'European magpie', the 'Eurasian collared-dove', and the 'Rose-ringed parakeet'. When  $P < 0.05$ , statistics are shown in bold.

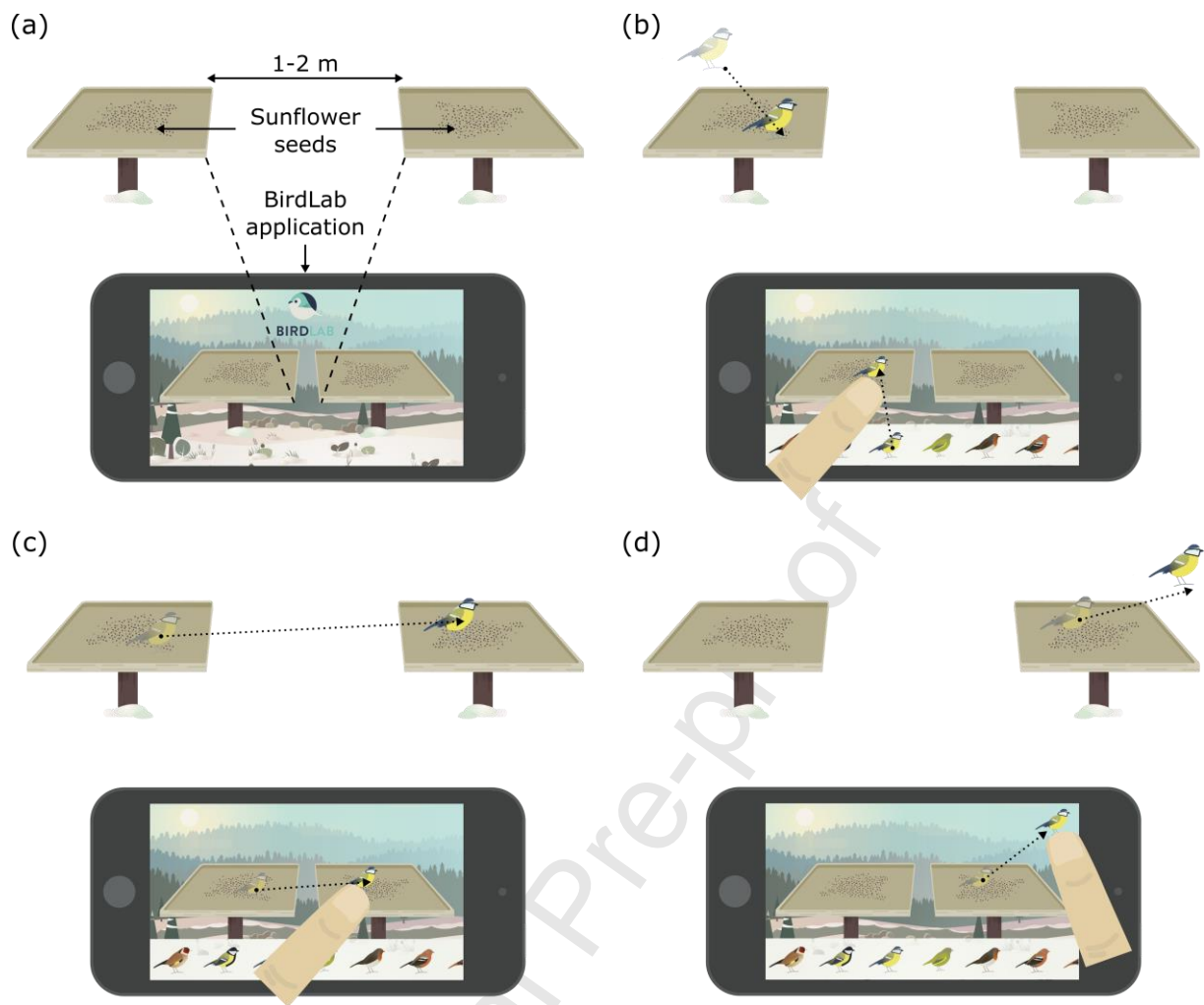
Response variable	Explanatory variable	Estimate	SE	<i>P</i>
Cumulative presence time	Winter 2018/2019 (vs 2017/2018)	0.189	0.130	0.146
	January (vs December)	0.189	0.105	0.073
	February (vs December)	0.236	0.123	0.055
	Confirmed (vs Amateur)	0.329	0.234	0.160
	Expert (vs Amateur)	<b>0.463</b>	<b>0.198</b>	<b>0.019</b>
	EM (vs absent treatment)	-0.330	0.203	0.103
	ECD (vs absent treatment)	<b>-0.402</b>	<b>0.148</b>	<b>0.007</b>
	RRP (vs absent treatment)	<b>-0.580</b>	<b>0.201</b>	<b>0.004</b>
	Longitude	-0.197	0.121	0.115
	Latitude	-0.107	0.112	0.346
Richness	Winter 2018/2019 (vs 2017/2018)	<b>-0.287</b>	<b>0.124</b>	<b>0.021</b>
	January (vs December)	0.163	0.102	0.109
	February (vs December)	-0.008	0.119	0.948
	Confirmed (vs Amateur)	<b>0.694</b>	<b>0.222</b>	<b>0.002</b>
	Expert (vs Amateur)	<b>0.820</b>	<b>0.188</b>	<b>&lt;0.001</b>
	EM (vs absent treatment)	-0.250	0.196	0.203
	ECD (vs absent treatment)	<b>-0.437</b>	<b>0.143</b>	<b>0.002</b>
	RRP (vs absent treatment)	-0.133	0.195	0.496
	Longitude	<b>-0.234</b>	<b>0.093</b>	<b>0.019</b>
	Latitude	-0.080	0.088	0.367

**Table 3. Results of the mixed-effect model for the species exclusive occupancy of a station.** Predictors' estimates are shown, along with their associated standard errors (SE), and *P*-values adjusted for multiple testing using the false discovery rate control (FDR adj. *P*). 'Cumul. pres. time of other species' and 'RRP' respectively stand for 'Cumulative presence time of other species' and the 'Rose-ringed parakeet'. When FDR adj. *P*<0.05, statistics are shown in bold.

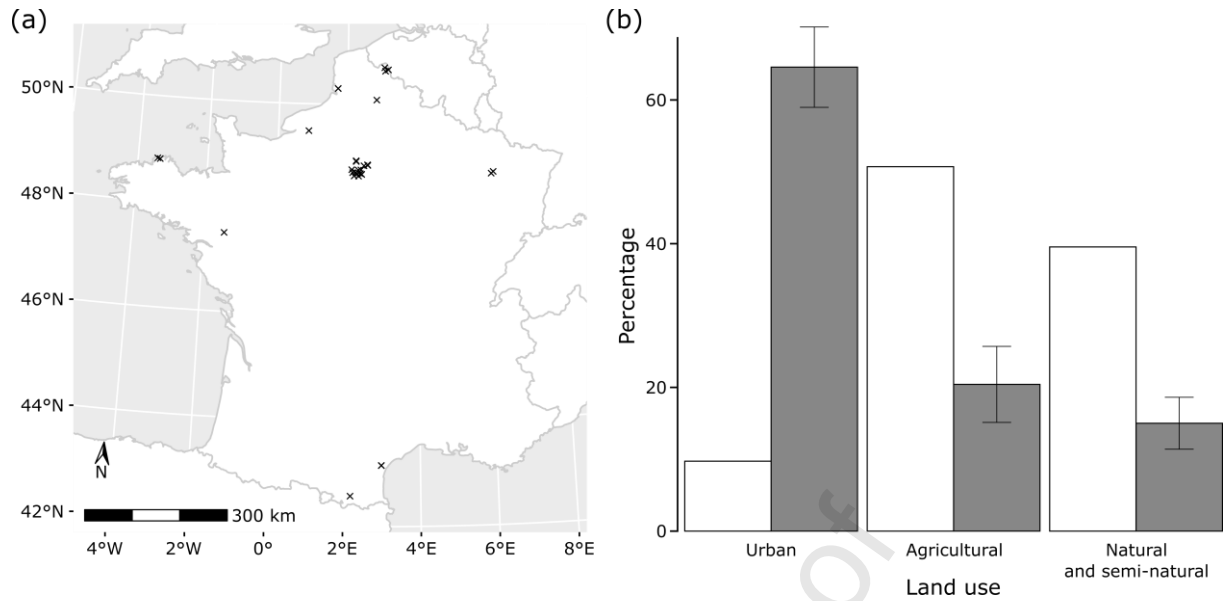
Response variable	Explanatory variable	Estimate	SE	FDR adj. <i>P</i>
Exclusive occupancy of a station	Winter 2018/2019 (vs 2017/2018)	<b>-0.299</b>	<b>0.088</b>	<b>0.001</b>
	January (vs December)	-0.032	0.066	0.676
	February (vs December)	<b>-0.211</b>	<b>0.080</b>	<b>0.015</b>
	Confirmed (vs Amateur)	0.261	0.153	0.131
	Expert (vs Amateur)	0.254	0.125	0.072
	Cumul. pres. time of other species	<b>-0.002</b>	<b>0.000</b>	<b>&lt;0.001</b>
	Crested Tit (vs RRP)	<b>-2.164</b>	<b>0.304</b>	<b>&lt;0.001</b>
	Coal Tit (vs RRP)	<b>-1.868</b>	<b>0.301</b>	<b>&lt;0.001</b>
	Eurasian Nuthatch (vs RRP)	<b>-1.566</b>	<b>0.327</b>	<b>&lt;0.001</b>
	European magpie (vs RRP)	<b>-1.563</b>	<b>0.322</b>	<b>&lt;0.001</b>
	Marsh Tit (vs RRP)	<b>-1.541</b>	<b>0.327</b>	<b>&lt;0.001</b>
	Great Tit (vs RRP)	<b>-1.420</b>	<b>0.235</b>	<b>&lt;0.001</b>
	Eurasian Blue Tit (vs RRP)	<b>-1.330</b>	<b>0.235</b>	<b>&lt;0.001</b>
	Dunnock (vs RRP)	<b>-1.311</b>	<b>0.270</b>	<b>&lt;0.001</b>
	Eurasian Blackbird (vs RRP)	<b>-1.298</b>	<b>0.332</b>	<b>&lt;0.001</b>
	European Robin (vs RRP)	<b>-1.214</b>	<b>0.250</b>	<b>&lt;0.001</b>
	House Sparrow (vs RRP)	<b>-1.102</b>	<b>0.246</b>	<b>&lt;0.001</b>
	Hawfinch (vs RRP)	-0.538	0.350	0.163
	European Greenfinch (vs RRP)	-0.463	0.253	0.106
	Common Chaffinch (vs RRP)	-0.130	0.242	0.676
	Eurasian Collared-Dove (vs RRP)	0.140	0.274	0.676
	European Goldfinch (vs RRP)	0.245	0.293	0.502
	Longitude	-0.002	0.035	0.962
	Latitude	0.017	0.036	0.676

**Table 4. Results of the generalised mixed-effects models.** Predictors' estimates (Est.) are shown, along with their associated standard errors (SE), and *P*-values (*P*). 'Cumul. pres. time oth. small sp.', 'EM', 'ECD' and 'RRP' respectively stand for 'Cumulative presence time of other small species', the 'European magpie', the 'Eurasian collared-dove', and the 'Rose-ringed parakeet'. When  $P < 0.05$ , statistics are shown in bold.

Response variable	Explanatory variables																	
	Winter 2018/2019 (vs 2017/2018)			January (vs December)			February (vs December)			Confirmed (vs Amateur)			Expert (vs Amateur)			Cumul. pres. time oth. small sp.		
	Est.	SE	P	Est.	SE	P	Est.	SE	P	Est.	SE	P	Est.	SE	P	Est.	SE	P
Presence of the:																		
European greenfinch	<b>2.805</b>	<b>0.476</b>	<b>&lt;0.001</b>	<b>1.226</b>	<b>0.304</b>	<b>&lt;0.001</b>	<b>1.771</b>	<b>0.379</b>	<b>&lt;0.001</b>	0.380	0.899	0.672	0.058	0.571	0.920	<b>0.001</b>	<b>0.000</b>	<b>0.008</b>
Common chaffinch	0.706	0.363	0.052	<b>0.739</b>	<b>0.292</b>	<b>0.011</b>	0.476	0.321	0.138	-1.250	0.839	0.136	-0.653	0.714	0.360	<b>0.001</b>	<b>0.000</b>	<b>0.042</b>
House sparrow	<b>1.817</b>	<b>0.554</b>	<b>0.001</b>	-0.088	0.341	0.796	-0.604	0.398	0.129	1.819	1.026	0.076	1.130	0.738	0.126	<b>0.002</b>	<b>0.001</b>	<b>&lt;0.001</b>
European robin	-0.563	0.289	0.051	-0.174	0.236	0.462	0.391	0.262	0.135	<b>0.947</b>	<b>0.462</b>	<b>0.041</b>	-0.344	0.430	0.423	<b>-0.001</b>	<b>0.000</b>	<b>0.002</b>
Eurasian blue tit	<b>-0.976</b>	<b>0.243</b>	<b>&lt;0.001</b>	-0.044	0.230	0.850	<b>-0.527</b>	<b>0.258</b>	<b>0.041</b>	-0.156	0.426	0.715	0.289	0.382	0.449	0.000	0.000	0.403
Great tit	<b>-1.032</b>	<b>0.264</b>	<b>&lt;0.001</b>	-0.285	0.218	0.191	<b>-0.705</b>	<b>0.252</b>	<b>0.005</b>	0.289	0.461	0.530	<b>0.999</b>	<b>0.397</b>	<b>0.012</b>	<b>-0.001</b>	<b>0.000</b>	<b>0.003</b>
Other small species	<b>-0.613</b>	<b>0.262</b>	<b>0.019</b>	<b>0.537</b>	<b>0.207</b>	<b>0.010</b>	0.112	0.241	0.641	<b>1.220</b>	<b>0.526</b>	<b>0.020</b>	<b>1.874</b>	<b>0.428</b>	<b>&lt;0.001</b>	0.000	0.000	0.134
	EM (vs absent treatment)			ECD (vs absent treatment)			RRP (vs absent treatment)			Longitude			Latitude					
	Est.	SE	P	Est.	SE	P	Est.	SE	P	Est.	SE	P	Est.	SE	P			
Presence of the:																		
European greenfinch	-0.877	0.506	0.083	0.080	0.509	0.875	0.659	0.669	0.324	-0.304	0.243	0.212	-0.236	0.211	0.264			
Common chaffinch	0.757	0.633	0.231	-0.163	0.477	0.732	0.779	0.544	0.153	-0.245	0.253	0.332	0.273	0.278	0.327			
House sparrow	0.330	0.442	0.456	<b>1.178</b>	<b>0.434</b>	<b>0.007</b>	-	-	-	-0.139	0.293	0.636	0.053	0.383	0.890			
European robin	0.573	0.386	0.137	-0.296	0.344	0.388	<b>-2.521</b>	<b>1.043</b>	<b>0.016</b>	<b>-0.176</b>	<b>0.070</b>	<b>0.013</b>	<b>0.228</b>	<b>0.103</b>	<b>0.027</b>			
Eurasian blue tit	<b>-1.204</b>	<b>0.381</b>	<b>0.002</b>	<b>-1.060</b>	<b>0.283</b>	<b>&lt;0.001</b>	-0.654	0.394	0.096	-0.142	0.078	0.067	-0.008	0.085	0.923			
Great tit	0.010	0.373	0.979	<b>-0.870</b>	<b>0.292</b>	<b>0.003</b>	-0.151	0.443	0.733	0.123	0.112	0.272	0.091	0.111	0.413			
Other small species	-0.617	0.388	0.112	-0.122	0.332	0.713	0.397	0.427	0.353	-0.233	0.151	0.123	<b>-0.337</b>	<b>0.148</b>	<b>0.023</b>			



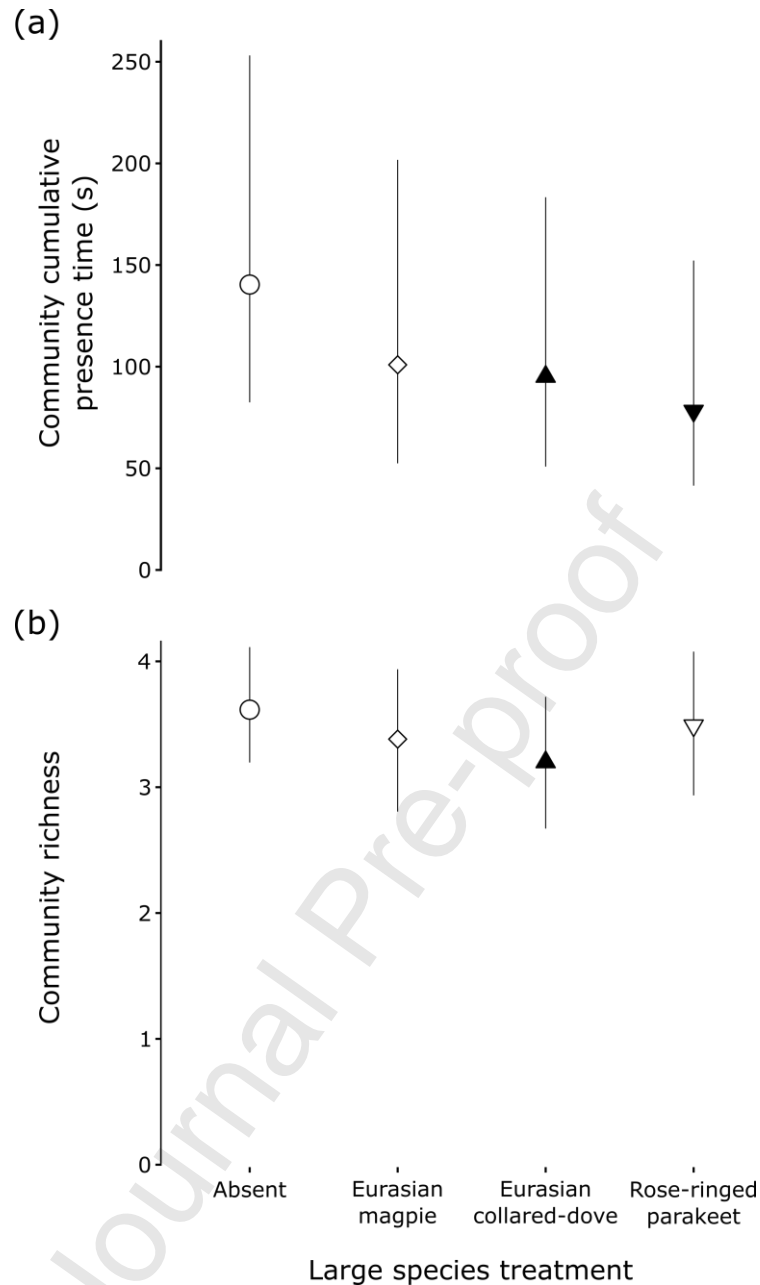
**Figure 1. BirdLab protocol.** Panel (a) shows how the station is represented in the BirdLab application. In (b-d), a blue tit individual respectively lands on the left birdfeeder, shifts from the left to the right birdfeeder, and leaves the station; each of these events is mimicked by the volunteer on the BirdLab application.



**Figure 2. Localisation of the 33 BirdLab stations.** In (a), crosses correspond to the stations.

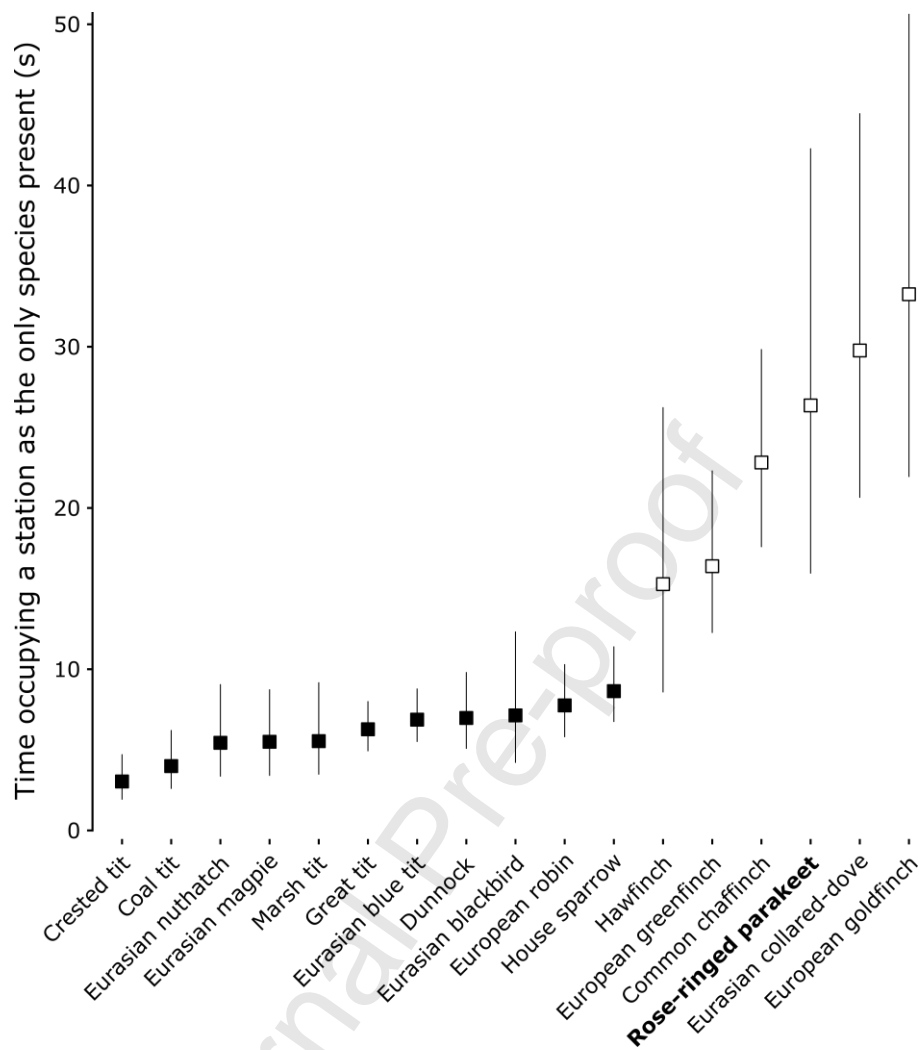
In (b), using the Theia OSO Land Cover Map 2018 (Inglada et al., 2018), we characterized the land use context of the stations, distinguishing between ‘Urban’ (categories 1-4), ‘Agricultural’ (categories 5-15) and ‘Natural and semi-natural’ (categories 16-22) areas.

White bars provide the percentage of France occupied by the three land use categories, and grey bars are the average land use found within 1 km of the 33 stations of our dataset (error bars are standard errors).

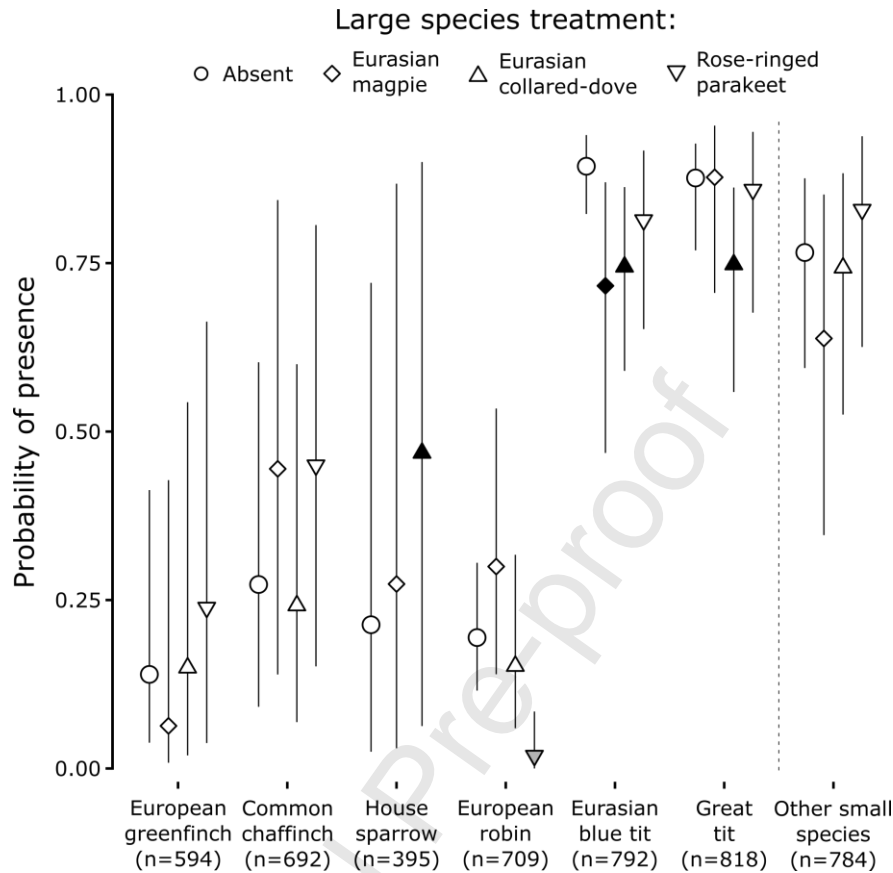


**Figure 3. Community-wide changes in the presence of large species.** Average community cumulative presence time (a) and richness (b) at a station during a session under four different conditions: the absence of any large species (circles) and presence of the Eurasian magpie (diamonds), the Eurasian collared-dove (upward triangles) or the Rose-ringed parakeet (downward triangles). Symbols are filled in black when estimates are significantly different (Table 2) from the ‘Absent’ treatment. Bars are 95% confidence intervals estimated from the models, using R package *ciTools* (Haman and Avery, 2019).





**Figure 4. Species exclusive occupancy of a station per session.** Squares are estimates (from mixed-effects linear models; see Methods) of time (in s) species occupied a station as the only species present during a session. Symbols are filled in black when the time is significantly different from the Rose-ringed parakeet (bold font), and empty otherwise (Table 3). Bars are 95% confidence intervals estimated from the model, using R package *ciTools* (Haman and Avery, 2019).



**Figure 5. Associations between small species and large species presence.** Probability of presence in a session for six small species and the group of 12 other small species, under the four large species treatment. Symbols are filled in grey or black when the probability of presence is significantly associated with the presence of a large species ( $P < 0.05$  and  $P < 0.01$  respectively; Table 4). The six separate small species are ordered from left to right by the median time of presence during a session (Table 1), and sample sizes ( $n$ ) are provided below each species name. Bars are 95% confidence intervals estimated from the models, using R package *ciTools* (Haman and Avery, 2019). Effect of the Rose-ringed parakeet on the House sparrow could not be estimated (see 2.3.3).

**CREDIT AUTHOR STATEMENT**

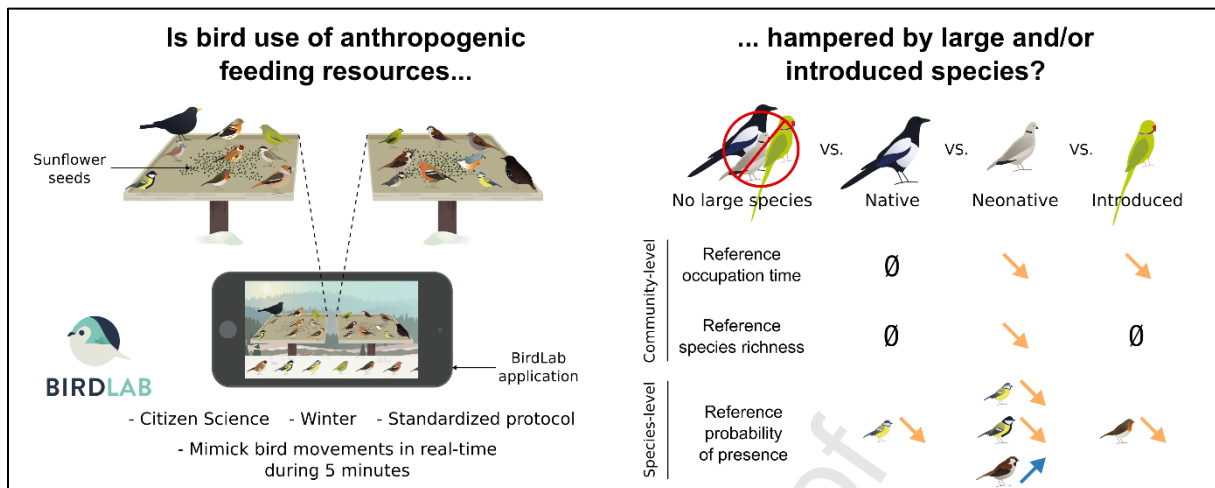
**Nicolas Deguines:** Conceptualization, Methodology, Formal Analysis, Visualization, Writing - Original Draft, Writing - Reviewing and Editing. **Romain Lorrilliere:** Conceptualization, Data Curation, Methodology, Monitoring Scheme Management, Writing - Reviewing and Editing. **Anne Dozières:** Monitoring Scheme Management, Writing - Reviewing and Editing. **Carmen Bessa-Gomes:** Conceptualization, Funding acquisition, Methodology, Monitoring Scheme Management, Writing - Reviewing and Editing. **François Chiron:** Conceptualization, Funding acquisition, Methodology, Monitoring Scheme Management, Writing - Reviewing and Editing.

#### **Declaration of competing interests**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Graphical abstract



## HIGHLIGHTS

- Citizen scientists record birds at birdfeeders through a serious game
- Community effects of Rose-ringed parakeet were compared with two similar species
- Bird community use of feeding resources was hampered by two of three large species
- Each large species differently affected other species' use of birdfeeders
- Garden bird feeding may not greatly favor introduced over native bird species