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Ecological factors influencing the breeding performance of great tits (*Parus major*) in artificial nest boxes

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Abstract: Installing an artificial nest box has a positive effect on the cavity nesters such as great tit (*Parus major*). Beyond the process of installing an artificial nest box, a study on the effect of ecological factors on breeding performance is necessary. This study was conducted to evaluate the ecological factors influencing breeding performance of great tits (*Parus major*) in artificial nest boxes in temperate mixed forests. In this study, the first egg-laying date and percentage of shrub were closely related among ecological factors. Variable influencing clutch size was date of first egg-laying date. Percentage of shrub had a positive relation to hatching success and fledgling success. First egg-laying date may represent quality of parental individuals. In addition, shrub can provide better food resources and has an impact on hatching success and fledgling success. These results suggest that higher quality of parental individual predominates the better the foraging site for enhancing breeding success. Also, managing shrubs in the forest appear to have a positive effect on breeding performance. Moreover, long-term ecological research is needed for the conservation of the birds and their habitats.

Key words: Clutch size, first egg-laying date, fledgling success, hatching success, shrub

1. Introduction

Urbanization poses challenges to natural ecosystems (Kaniewski et al., 2013). Changes in natural ecosystems due to urbanization include a reduction of size and quality of ecosystem habitats, which has negative effects on wildlife (Alvey, 2006). In forest areas, environmental impacts of urbanization may involve the conversion of land use (Sejati et al., 2018). As the world becomes more urbanized, urban forest areas will become more important for protecting biodiversity (Alvey, 2006). Recently, urbanization has gained new interest because of ecological interactions in urban environments (Bateman et al., 2013).

Urban forests often lack large trees, which are used by cavity-nesters (Stagoll et al., 2012). Accordingly, installing artificial nest boxes can provide nesting resources for cavity-nesters in urban forests. Artificial nest boxes can be useful for avian conservation (Lambrechts et al., 2010) and have been broadly used to investigate the breeding ecology of small birds such as great tits (*Parus major*), which can adapt to live in various environments (Matthew et al., 2002).

Great tits are widely distributed in Europe and Asia and are one of the abundant bird species in forests. Great tits are insectivorous, using arthropods as a food resource, especially during the breeding season (Seress et al., 2018). Nutritional factors are known critical determinants of occurrence patterns of insectivorous birds (Razeng and Watson, 2015). Detailed research is needed to identify the conservation measures that provide optimal ecological conditions and resources for great tits (Gracía et al., 2021). Moreover, understanding their breeding ecology is essential for the conservation of great tits and their habitats.

Great tit breeding parameters can be described as clutch size, brood size, and fledgling number (Seki and Takano, 1998). These characteristics can be affected by various ecological factors. The egg-laying dates of great tits are closely related to the emergence of arthropods (Nilsson and Raberg, 2001). Plant flowering, which offers food resources for arthropods, varies according to altitude and temperature (Bonamour, 2021). In addition, proximity to roads is associated with artificial nest survival (Downing et al., 2015; da Silva et al., 2019).

Various kinds of research on great tit have been continuously conducted in the world. However, in South Korea, not enough information exists concerning ecological factors affecting great tit breeding performance. In this study, we aimed to understand how ecological variables affect great tit breeding performance. We hypothesized that habitat factors (percentage of shrub,

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downed tree, and grass cover), roads, and first egg-laying dates all affect breeding performance. We then investigated the relationship between ecological variables and the clutch size, hatching success, and fledgling success of great tits.

2. Materials and methods

This study was conducted in two mixed forests (37°00'04"N, 127°13'96"E) from March 2019 to July 2021 in Ansung Campus, Chung-Ang University, South Korea. Great tit (*Parus major*), brown-eared bulbul (*Hypsipelia amaurotis*), great spotted woodpecker (*Dendrocopus major*), and Eurasian nuthatch (*Sitta europaea*) were the dominant bird species in the study area. Rigida pine (*Pinus rigida*), Japanese red pine (*Pinus densiflora*), zelkova tree (*Zelkova serrate*), and ginko (*Ginko biliba*) were the dominant tree species in the study area. The annual mean temperature is 12.7 °C and annual precipitation is 1169 mm. The altitudinal gradient range is 40–50 m above sea level.

In each of the two sites, 48 artificial nest boxes were installed, meaning that 96 nest boxes were installed in total. For a total of 3 years, 73 artificial nest boxes were used by great tit (2019, n = 28; 2020, n = 24; 2021, n = 21). The nest boxes used in this study were all 15 × 13 × 26 cm. All artificial nest boxes were installed at a height of 1–2 m from the ground at an interval of every 30 m (Rhim et al., 2013). The nest box entrance diameter was either 30 mm, 35 mm, or 40 mm. The location of artificial nest boxes was recorded by a GPS device (GPSMAP 64s, Garmin, Lenexa, KS, USA). Recorded locations were used to estimate the distance from roads using QGIS v.3.20.0.

The percentage of shrub, downed tree, and grass cover was calculated to examine habitat factors. We measured habitat factors of each artificial nest box within a radius of 5.64 m, which can represent the overall habitat structure (Lee et al., 2017). Artificial nest boxes were visited 3–5 days per week during the experiment periods. Visits to artificial nest boxes were always conducted in the morning. The first egg-laying date was recorded as the day that the first egg was observed, assuming one egg was laid per day (Perrins, 1980). If there were two eggs at the first visit, the first egg-laying date was recorded as one day before. Clutch size was measured (mean ± SE, 8.66 ± 0.25) as the maximum number of eggs observed in a given nest box over any visit. Since the number of nestlings (mean ± SE, 6.65 ± 0.50) varies according to clutch size, the hatching success (ratio of hatched nestlings over clutch size) of each nest was calculated. Same as hatching success, the number of fledglings (mean ± SE, 4.20 ± 0.54) varies according to brood size, and the fledgling success (ratio of fledglings surviving over the total number of nestlings) of each nest was calculated too. Field surveys were not conducted in extreme weather such as rain and strong wind.

Clutch size, hatching success, and fledgling success were selected as dependent variables. Habitat factors (percentage of shrub, downed tree, and grass cover), distance from the road, and first egg-laying date were selected as independent variables. In addition, to analyze the effect of year and study sites, both year and site were included as independent variables.

The multicollinearity between independent variables were selected and removed using the Spearman rank sum test. We selected one variable in each pair ($|r| > 0.7$), that had a higher correlation with dependent variables or more ecological meaning (Suttidate et al., 2019). A generalized linear model (GLM) was used to determine which ecological factors affected clutch size, hatching success, and fledgling success (R package: lme4; Bates et al., 2015). GLM was carried out considering the characteristics of the dependent variables (clutch size, Poisson distribution, hatching success, binomial distribution, fledgling success, binomial distribution). The corrected Akaike information criterion (AIC*c*) was used for model selection within GLMs (R package: MuMIn; Bartoń, 2016). We selected models with AIC*c* value less than 2. AIC*c* model weights of the selected models according to the clutch size (w_i, 0.06–0.27), hatching success (w_i, 0.18–0.41), and fledgling success (w_i, 0.14–0.23) were determined. Moreover, we calculated the averaged regression coefficient using the MuMin R package to improve model prediction ($\Delta AICc < 2$). Statistical significance was defined as $p < 0.05$.

3. Results

Data analysis was conducted using data from 73 artificial nest boxes that were used for 3 years. In this study, only great tits bred in artificial nest boxes. Major nest failure was dead of chicks (19%), nest abandonment (14%), and predation by snakes (67%). The first model included first egg-laying date, which the second model included first egg-laying date and distance from road, and the third model included first egg-laying date and percentage of downed trees (Table 1). The first egg-laying date was present in all models (Table 1). After model selection, the three best models were averaged. In the model average, only the first egg-laying date significantly influenced clutch size (β = –2.2114, Z = –3.06, $p < 0.01$). Distance from the road (β = 0.0008, Z = 0.81, p = 0.42) and percentage of downed trees (β = –0.0026, Z = –0.46, p = 0.65) were not significant factors influencing clutch size (Table 2).

The first model included percentage of shrub, percentage of downed trees, and percentage of grass (Table 3). The second model included percentage of shrub and percentage of grass (Table 3). Percentage of shrub existed in all models (Table 3). As was performed with clutch size GLMs, the three best hatching success models were averaged. Percentage of shrub significantly influenced

Table 1. Generalized linear models built to determine the ecological factors affecting clutch size of great tits (*Parus major*) in Ansung Campus, Chung-Ang University. This table lists candidate models with ΔAIC*c* < 2.

Model	AIC*c*	ΔAIC*c*	w_i	K
[Intercept + fe]	325.90	0.00	0.27	3
[Intercept + fe + dr]	327.41	1.51	0.07	4
[Intercept + fe + dt]	327.86	1.96	0.06	4

w_i: Akaike weight; fe: first egg-laying date; dr: distance from the road; dt: percentage of downed trees.

Table 2. Averaged model describing the ecological factors affecting the clutch size of great tits (*Parus major*) in Ansung Campus, Chung-Ang University.

Factors	*β*	SE	*Z*	p
Intercept	6.70	1.46	4.52	<0.01
fe	–2.21	0.71	–3.06	<0.01
dr	0.00	0.00	0.81	0.42
dt	–0.00	0.00	–0.46	0.65

SE: standard error; fe: first egg-laying date; dr: distance from the road; dt: percentage of downed trees.

Table 3. Generalized linear models built to determine the ecological factors affecting hatching success of great tits (*Parus major*) in Ansung Campus, Chung-Ang University. This table lists candidate models with ΔAIC*c* < 2.

Model	AIC*c*	ΔAIC*c*	w_i	K
[Intercept + sh + dt + gr]	90.41	0.00	0.41	5
[Intercept + sh + gr]	92.03	1.62	0.18	4

w_i: Akaike weight; sh: percentage of shrub; dt: percentage of downed trees; gr: percentage of grass.

Table 4. Averaged model describing the ecological factors affecting hatching success of great tits (*Parus major*) in Ansung Campus, Chung-Ang University.

Factors	*β*	SE	*Z*	p
Intercept	–2.52	0.81	–3.01	<0.01
sh	0.04	0.01	2.49	0.01
dt	0.05	0.04	1.45	0.15
gr	0.01	0.01	1.29	0.20

SE: standard error; sh: percentage of shrub; dt: percentage of downed trees; gr: percentage of grass.

hatching success (β = –0.04, Z = 2.49, p = 0.01), but percentage of downed trees (β = 0.05, Z = 1.45, p = 0.15) and percentage of grass (β = 0.01, Z = 1.29, p = 0.20) were not significantly factors (Table 4).

The first model included percentage of shrub and percentage of downed trees, while the second model only included percentage of shrub (Table 5). The third model included percentage of shrub, percentage of downed trees, and distance from the road, and the fourth model included percentage of shrub and distance from the road (Table 5). As with hatching success GLMs, the percentage of shrub was considered in all models (Table 5). In the average of the four models, neither distance from the road (β = 0.01, Z = 1.31, p = 0.19) nor percentage of downed trees (β = 0.05, Z = 1.19, p = 0.24) significantly influenced fledgling success. However, percentage of shrub (β = 0.05, Z = 1.19, p = 0.02) was as a significant factor in fledgling success (Table 6).

4. Discussion

In this study, the first egg-laying date and percentage of shrub were found to have high influence over breeding success among ecological factors. In other words, the food resources from the shrub and quality of parental individuals inferred from the first egg-laying date were the ecological factors affecting the breeding performance of great tits.

The primary variable influencing clutch size was the date of first egg-laying. The first egg-laying date has been reported to have a close relationship with the quality of the parent (Álvarez and Barba, 2008). Higher parent quality can be an advantage in nest selection. Thereafter, high-quality parents prepare the nest faster than other parents (Mainwaring and Hartley, 2008). Parental individuals could also benefit from more opportunities for foraging during arthropod emergence. Moreover, early completion of nest preparation can accelerate the first egg-laying date (der Weduwen et al., 2021).

Egg-laying is energetically costly, as it increases metabolic rates (Nilsson and Raberg, 2001; Vezina and Williams, 2002) and the need for food resources (Visser et al., 2006). Consequently, finding adequate food resources during egg-laying periods is essential. Moreover, the energy great tits expend while gathering food can vary according to the food availability in each local habitat (te Marvelde et al., 2012). High-quality parents have better access to food resources, which leads to laying more eggs than

Table 5. Generalized linear models built to determine the ecological factors affecting fledgling success of great tits (*Parus major*) in Ansung Campus, Chung-Ang University. This table lists candidate models with ΔAIC*c* < 2.

Model	AIC*c*	ΔAIC*c*	w_i	K
[Intercept + sh + dt]	50.05	0.00	0.23	4
[Intercept + sh]	50.45	0.40	0.18	3
[Intercept + sh + dt + dr]	50.62	0.58	0.17	5
[Intercept + sh + dr]	51.01	0.95	0.14	4

w_i: Akaike weight; sh: percentage of shrub; dt: percentage of downed trees; dr: distance from the road.

Table 6. Averaged model describing the ecological factors affecting fledgling success of great tits (*Parus major*) in Ansung Campus, Chung-Ang University.

Factors	*β*	SE	*Z*	p
Intercept	−4.69	1.42	−3.26	<0.01
sh	0.05	0.02	2.36	0.02
dt	0.05	0.04	1.19	0.24
dr	0.01	0.01	1.31	0.19

SE: standard error; sh: percentage of shrub; dt: percentage of downed trees; dr: distance from the road.

other parents (Nilsson and Raberg, 2001). In this study, the first egg-laying date affected clutch size, which may be explained by a higher-quality parental individual having an advantage over others in intraspecific competition.

The percentage of shrub had a positive relationship with both hatching success and fledgling success. During the great tit breeding season, shrubs act as foraging sites (Mackenzie et al., 2014). In general, the great tit consumes a wide breadth of food resources. However, high protein foods are required for egg-laying, incubation, and rearing during the breeding season (Perrins, 1991). For this reason, arthropods are major food resources for both parental individuals and broods during breeding season (Razeng and Watson, 2015). Shrubs have various arthropods that emerge in spring and also provide great tits with shelter from predators (Veselý et al., 2016). In the Mediterranean mixed forests, blue tit (*Cyanistes caeruleus*) preferred shrubs as a foraging site over great tit (Díaz et al., 1998). However, blue tit was not distributed in the temperate forests of South Korea. Therefore, these results suggest that a high proportion of food resources distributed in shrubs played an essential role in both hatching success and fledgling success.

Distance from the road, percentage of downed trees, and humidity were included as variables in model averages but never significantly influenced breeding success. Many studies have been conducted on the relationship between roads and avian breeding (Reijnen et al., 1995; Halfwerk et al., 2011). Traffic noise around roads can disturb acoustic communication during the breeding season (Summers et al., 2011). Moreover, the noise can distract individual birds and anti-predator vigilance may increase, putting birds at higher risk of predation (Quinn et al., 2006; Yim-Hol Chan et al., 2010). In another study, nest selection near roads was associated with poor breeding success (de Gregorio et al., 2014). However, in this study, distance from the road was not a significant factor explaining the breeding of great tits. This result may stem from the small scale of roads in the study area limiting any effect on the birds (Forman et al., 2002). On the other hand, other studies have focused on large-scale roads such as highways (Xie et al., 2021).

Arthropods that serve as food resources are especially abundant in downed trees (Schieck et al., 1995). In a habitat with a high proportion of downed trees, the absence of a canopy increases shrub cover. Also, the grass is used as forage sites during the breeding season (Kuranov, 2009). But the short size of plants can enhance the predation risks to birds (Whittingham and Evans, 2004). Therefore, it is considered that great tits primarily forage in shrubs.

In conclusion, the first egg-laying date and coverage of shrub significantly affected the breeding performance of great tits. The first egg-laying date may represent the quality of parental individuals. In addition, shrubs can provide better food resources and affect both hatching success and fledgling success. These results suggest that higher-quality parents occupy better foraging sites for enhanced breeding success. Moreover, long-term ecological research is needed for the conservation of great tits and their habitats.

Data availability statement

All datasets used for this article are available from the public data repository at the website of https://doi.org/10.6084/m9.figshare.21589767.v3 (Lee et al., 2022).

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