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SHORT COMMUNICATION

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Atmospheric factors influence body and egg of great tits *Parus major*

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ABSTRACT
This study was conducted to investigate the influence of atmospheric factors on the body and egg of great tits (*Parus major*), which were bred in artificial nest boxes from March to July of 2012 and 2013. The mean temperature and relative humidity were significantly higher in the spring season of 2012 than in 2013. Body masses of incubating parent birds differed between both years. Eggs which were laid in 2012 were larger and heavier than those of 2013. Hue and saturation values for background and spot colors were significantly different between 2012 and 2013. In 2012, there were warmer and wetter atmospheric conditions, which may influence vegetation and food availability for the birds. The large, heavy, and less vividly-colored eggs were laid in 2012 by parents with good body condition. Results showed that spring atmospheric factors influenced both body and egg of great tits. Further studies on the relationships between atmosphere, vegetation, and food availability of the birds are needed.

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Body mass; color; humidity; temperature

Introduction

The variation, inter- and intra-specific variability, and its potential functionality of body condition and egg features, are topics that have attracted many avian ecologists (Kilner 2006; Krist and Grim 2007; Soler et al. 2008). Body mass and length of tarsus and wing can be representative of the condition and quality of the body (Gill 2007). In addition, egg coloration can indicate fertility of eggs, and egg size may be related to energy reserve mobilization in birds (Hwang 2014).

These egg characteristics can influence the physiological condition of adults and possibly serve as quality indicators for adult birds (Moreno and Osorno 2003; Martínez-de la Puente et al. 2007). Adults could be affected by food deficiency in their breeding territory (Lee et al. 2017). Nevertheless, the variation in the body and egg of birds is due to a combination of environmental, maternal, and genetic influences, and understanding this variation is important for testing the hypotheses that explain body and egg conditions (López de Hierro and De Neve 2010).

Because atmospheric conditions can determine foliage increase of vegetation and insect emergence, atmospheric factors are likely to influence food availability of insectivorous birds. Moreover, atmospheric conditions can play an important role for breeding birds. In this study, we tested the hypothesis that characteristics of body and egg are related to atmospheric conditions in great tits (*Parus major*). Great tits are socially monogamous passerines, songbirds, and are captivity-nesting (Lee et al. 2014). Great tits are excellent bird species for studies of egg and body characteristics because they can easily breed in artificial nest boxes (Lee et al. 2017). In addition, the eggs of great tits have a diverse range of sizes and pigment spots.

Regardless of the actual mechanism of how environmental factors affect the breeding of great tits, any evidence of a relationship between the atmosphere and great tits would suggest that atmospheric factors may potentially influence the breeding performance of these birds. The aim of this study was to investigate the influence of two atmospheric factors (temperature and relative humidity) on body and egg of great tits.

Methods

The study animals were selected from a free-living artificial nest box population of great tits from forests (37°00′N, 127°13′E) in Ansung Campus, Chung-Ang University, Ansung, Korea from March to July of 2012 and 2013. We selected two 120 × 240 m study sites. The dominant tree species in the study area were Mongolian oak (*Quercus mongolica*), serrata oak (*Q. serrata*), and pitch pine (*Pinus rigida*) (Hwang et al. 2015).

The atmospheric variables used to identify relationships between environmental conditions and great tits were mean temperature and relative humidity from 1 April to 30 June of 2012 and 2013. The data for atmospheric conditions were logged every hour using a Hobo data logger (Pro V2, Onset Computer Corporation) (Son et al. 2012; Hwang 2014). We have chosen this period for considering atmospheric conditions because we did not know whether eggs were related to body condition at the time of egg laying or if they were indirectly dependent on food availability, which can be influenced by a relatively long time period (Avilés et al. 2007).

Both study sites were divided into 30 × 30 m grids marked with flags, which facilitated the accurate identification of the location of the artificial nest boxes. A total of 90 wooden artificial nest boxes (16 × 15 × 30 cm) with 1.5 cm thick walls were placed in trees 1–2 m above the ground (Rhim et al. 2008).

In this study, the presence of eggs defined the artificial nest box as a breeding nest box (Son et al. 2012). The breeding nest boxes were investigated five to six times per week. The dates of egg appearance, laying order, and clutch size

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were recorded (López de Hierro and De Neve 2010). We measured 290 eggs from 40 clutches laid by different females. Eggs were measured on the day they were laid in terms of length (major axis) and width (minor axis) with a vernier caliper (Mitutoyo 530-108, Mitutoyo Corporation) to the nearest 0.05 mm (Moreno et al. 2004). Eggs were weighed on an electronic balance (SPE 602 Ohaus Scout Pro Portable Electric Balance, Ohaus) to the nearest 0.01 g. Shape and size indices of eggs were calculated by the following equations:

- Shape index = length of major axis/length of minor axis
- Size index = length of major axis × length of minor axis

Moreover, nests were visited daily during egg laying and photographs of each new egg were taken in a portable wooden box (20 × 15 × 18 cm) with an illuminated LED light source (20,000 lux). Adobe Photoshop CS5 was used to analyze photographs. In each photograph, background and spots of the eggs were separated. Color variables such as hue, saturation, and brightness of background and spots were measured (Hill 2002; Hill and McGraw 2006).

During the incubation of the birds in artificial nest boxes, we weighed parent birds with an electronic balance. The length of the tarsus was measured with vernier calipers (Sanz and Tinbergen 1999; Aslan and Yavuz 2010; Hwang 2014).

Data analysis was performed using SAS software (SAS Inst.). The Wilcoxon rank-sum test was used for the comparisons of atmosphere, tarsus length, and body mass between 2012 and 2013. We compared variables of egg shape, size, mass, and color using a Mann-Whitney U test. *P* values are presented, and all results are presented as mean ± SD (standard deviation).

Results

The mean temperature (Wilcoxon rank-sum test; $Z = -5.56$, $P = 0.001$) and relative humidity ($Z = -2.02$, $P = 0.04$) from 1 April to 30 June were significantly different between 2012 and 2013. In 2012 there were higher temperatures and wetter conditions compared to 2013 (Table 1).

There was no difference in tarsus length of great tits during incubation periods between 2012 and 2013 ($Z = -0.47$, $P = 0.64$). However, the mean value of body mass of parent birds was significantly different between both years ($Z = -3.30$, $P = 0.001$). In 2012, the mean value of body mass of parent birds was higher than that of 2013 (Table 2).

The variables of egg characteristics were significantly different between 2012 and 2013. The eggs that were laid in 2012 were larger than those in 2013. Shape (Mann-Whitney U test; $Z = -6.74$, $P = 0.01$) and size ($Z = -4.07$, $P = 0.01$) indices were significantly higher in 2012. Moreover, egg mass ($Z = -2.84$, $P = 0.01$) in 2012 was heavier than 2013 (Table 3).

The hue, saturation, and brightness were analyzed for the background and spot color of eggs. For the background color of eggs, hue ($Z = -4.75$, $P = 0.01$) and saturation ($Z = -8.71$, $P = 0.01$) were significantly different between 2012 and 2013. The hue of background color was higher in 2012 and saturation was higher in 2013. Brightness of background did not differ between the two years. In addition, there were significant differences in hue ($Z = -10.63$, $P = 0.01$) and saturation ($Z = -7.43$, $P = 0.01$) of egg spot color between 2012 and 2013. These variables were higher in 2013. However, there was no difference in spot brightness between 2012 and 2013 ($Z = -0.07$, $P = 0.95$) (Table 4).

Table 1. Differences in temperature and relative humidity (mean ± SD) of atmosphere from 1 April to 30 June between 2012 and 2013, analyzed with Wilcoxon rank-sum test.

	2012	2013	*Z*	*P*
Temperature (°C)	13.05 ± 5.58	11.83 ± 5.31	−5.56	0.001
Relative humidity (%)	70.15 ± 12.45	69.31 ± 13.13	−2.02	0.04

Table 2. Differences in tarsus length and body mass (mean ± SD) of incubating great tits between 2012 and 2013, analyzed with Wilcoxon rank-sum test.

	2012	2013	*Z*	*P*
Tarsus length (mm)	20.69 ± 1.02	20.49 ± 0.76	−0.47	0.64
Body mass (g)	14.30 ± 1.51	12.63 ± 1.76	−3.30	0.001

Table 3. Differences in egg shape, size, and mass (mean ± SD) of great tits between 2012 and 2013, analyzed with Mann-Whitney U test.

	2012	2013	*Z*	*P*
Shape index	0.77 ± 0.03	0.71 ± 0.04	−6.74	0.01
Size index	210.97 ± 12.15	202.12 ± 14.86	−4.07	0.01
Mass	1.45 ± 0.12	1.40 ± 0.15	−2.84	0.01

Table 4. Differences in coloration of background and spots (mean ± SD) in eggs of great tits between 2012 and 2013, analyzed with Mann-Whitney U test.

		2012	2013	*Z*	*P*
Background	Hue	111.32 ± 26.52	80.30 ± 16.45	−4.75	0.01
	Saturation	7.51 ± 1.17	14.39 ± 2.81	−8.71	0.01
	Brightness	73.09 ± 5.43	74.57 ± 6.45	−1.732	0.08
Spots	Hue	25.88 ± 6.09	34.36 ± 4.38	−10.63	0.01
	Saturation	46.68 ± 9.74	57.06 ± 7.01	−7.43	0.01
	Brightness	54.45 ± 6.53	54.12 ± 7.33	−0.07	0.95

Discussion

We predicted relationships between temperature, relative humidity, body mass, egg size, egg mass, and egg color. Our predictions were supported by the data, which showed that spring atmospheric factors affected the body and egg of great tits. More specifically, body masses of parent birds were heavier, egg size and mass were higher, and saturations of background and spot colors in egg were lower in spring 2012, when there were higher temperatures and relative humidity. Therefore, these results offer support for atmospheric factors' effects on the body mass of great tits. In particular, the saturation levels of background and spot colors in eggs were higher in 2013 than in 2012. We found that great tits in poor body condition laid vividly-colored eggs in 2012.

Egg mass has been reported to be positively associated with the body condition of the females that laid the eggs (Martínez-de la Puente et al. 2007). Moreover, males feed their mates during the laying period (Nilsson and Smith 1988); therefore, body condition of males may influence egg quality as well. Body condition and immunocompetence of adults, and also those of nestlings, are related to egg coloration in some birds (Siefferman et al. 2006; Soler et al. 2008).

There is an alternative explanation for the correlation of atmosphere with body mass and egg characteristics of great tits. High temperatures and relative humidity may result in dense forest vegetation. Because of the dense vegetation, insect emergence may increase, and food availability for birds would increase as well. In this study, there were lack of data on vegetation change caused by temperature and relative humidity, and this could be a limitation of this study. Although we did not collect data on vegetation and food abundance, we can estimate the relationships between atmospheric factors, vegetation, food abundance, and conditions of body and egg of great tits. In this scenario, temperature and humidity directly affect development of insects and indirectly affect vegetation at a local scale (Sillett et al. 2000; Jones et al. 2003; Avilés et al. 2007). These direct and indirect effects of atmospheric conditions influence the body mass of adults and the capacity of females to invest in the size, mass, and color of eggs.

Status of body at the egg laying period could be affected by environmental conditions. Atmospheric factors may particularly influence body mass and egg characteristics by their direct effects on the physiological status of birds (Joseph et al. 1999; Avilés et al. 2006; Siefferman et al. 2006). Direct or indirect effects of atmospheric factors may induce atmospheric effects on the body and egg of great tits (Avilés et al. 2007). We found that both egg mass and coloration covary positively with body condition of adults, suggesting that both egg mass and coloration reflect the quality of the parents (Siefferman et al. 2006; Sanz and Gracía-Navas 2009).

For most birds, the outer layer of the eggshell is covered by pigments (Avilés et al. 2007). Shell pigmentation may have an adaptive value for eggs and birds (Avilés et al. 2006). Previous studies have related the color of eggs to good immune capacity and body condition in females (Moreno et al. 2004, 2006). In 2013, the poorer body condition of females was accompanied by higher pigment accumulation in eggshells. Higher pigment accumulation induces higher saturation levels for egg color (Martínez-de la Puente et al. 2007). There is evidence that egg color is related to poor body condition of females, which is influenced by environmental factors such as temperature and rainfall (Moreno et al. 2005).

Conclusions

We found that spring atmospheric factors affected the body mass and egg characteristics of great tits. Body mass and egg conditions seem to be limited characteristics for this bird. These findings are in agreement with predictions that atmospheric factors may play an important role in the successful breeding of this species. However, further studies are needed to determine the relationship between atmosphere, vegetation, and food availability for these birds.

Disclosure statement

No potential conflict of interest was reported by the authors.

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