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Nest predators, nest-site selection and nest success of the Emei Shan Liocichla (*Liocichla omeiensis*), a vulnerable babbler endemic to southwestern China

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Abstract

Background: The Emei Shan Liocichla (*Liocichla omeiensis*) is a globally vulnerable babbler, endemic to southwestern China. We investigated its nest predators, nest-site selection and nest success at the Laojunshan National Nature Reserve in Sichuan, China in order to identify the precise nesting-habitat requirements of the species, and to test whether the nest-site-selection cues, preferred by the Emei Shan Liocichla, are positively associated with nest success.

Methods: We used infrared cameras to determine nest predators. We compared the microhabitat attributes between nest and random sites, as well as successful and failed nests. We used Binary Logistic Regression to determine the most important variables affecting nest-site selection of the Emei Shan Liocichla. We used the nest survival analysis in Program MARK to estimate daily nest survival rates (DSR). Nest success was calculated using the Mayfield method.

Results: In total 56 nests were found. The DSR for all nests that contained at least one egg was 0.9564 ± 0.0091 (95 % CI 0.9346–0.9711) ($n = 40$), while the total nest success was 27.5 %. We identified four categories of predators in 10 nest predation events, i.e. squirrels ($n = 5$), snakes ($n = 3$), raptors ($n = 1$) and wasps ($n = 1$). We found that: (1) nest predation was the primary reason for nest failure of the Emei Shan Liocichla, (2) tree cover, bamboo cover, liana abundance and distance to forest edge or gap were the most important variables affecting nest-site selection of this species, and (3) the nest-site-selection variables we measured appeared not to be positively associated with nest success.

Conclusions: Our findings suggest that the Emei Shan Liocichla tended to select nest sites near forest edges or gaps with good concealment and that nest-site selection by this species was nonrandom but not necessarily adaptive. Reducing forest-edge development and protecting bamboo stands should be effective for conservation of this species.

Keywords: Nest predator, Nest-site selection, Nest success, *Liocichla omeiensis*, Laojunshan Nature Reserve

Background

Studies on habitat selection have important implications for conservation of rare and endangered bird species (Chalfoun and Schmidt 2012; Rocha et al. 2013). Nest-site selection is a vital component of avian habitat selection (Cody 1985). It is thought that nest placement reflects selection for secure sites to minimize failure (Cancellieri and Murphy 2014). To date, the behavioral mechanisms of selection are poorly understood. Nest predation seems to be the primary source of nest losses across a broad range of avian species (Ricklefs 1969; Martin 1993a; Filliater et al. 1994; Thompson 2007). Nest predation is thus considered a key source of selection for birds (Martin 1995; Caro 2005; Ibáñez-Álamo et al. 2015). Many aspects of the nesting behavior of birds appear to be adaptations to avoid nest predation (Filliater et al. 1994; Mikula et al. 2014). As different predators locate nests using a variety of

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search methods and sensory cues (Liebezeit and George 2002), identification of the species of nest predators may provide important insights for a better understanding of avian nesting behavior (Ibáñez-Álamo et al. 2015).

The Emei Shan Liocichla (*Liocichla omeiensis*) is an endemic babbler in southwestern China (Lei and Lu 2006) and has been listed by the IUCN as a globally vulnerable species because of its small, declining population and fragmented range (BirdLife International 2016). The species largely inhabits bamboo and understory shrubs (Fu et al. 2013). In this study, we investigated its nest predators, nest-site characteristics and nest success as part of a wider study on the ecology of Emei Shan Liocichla. Our objectives were: (1) to ascertain the main species of nest predators, (2) to describe the characteristics of nest-site microhabitat, (3) to test whether the nest-site-selection cues preferred by the Emei Shan Liocichla are positively associated with nest success and (4) to use our results in order to make recommendations for the conservation management of this species.

Methods

Study site

The study was carried out at the Laojunshan National Nature Reserve (28°39′36″–28°43′38″N, 103°57′36″–104°04′12″E) in the southwest of China during the breeding seasons (April–August) of 2009–2011 and 2013–2014. The reserve is located at an elevation of 900–2009 m, with a temperate climate, high precipitation (>1500 mm per year) and relative humidity of >85 %. The vegetation in the reserve is characterized by an evergreen broadleaved forest with an abundant bamboo (*Chimonobambusa szechuanensis*) understory. The reserve is an important site within the restricted range of the Emei Shan Liocichla (Fu at al. 2011).

Field survey

Nests of the Emei Shan Liocichla were discovered by systematic searching, as well as by observing parental behavior and tracking breeding pairs (Martin and Geupel 1993). Nests were numbered when found and recorded with a hand-held GPS unit (eTrex Venture HC, Garmin). To determine nest predators, infrared cameras (Ltl 6210, Acorn) were placed ~1 m from some nests at the nestling stage or late incubation period when the adults would not abandon their nests easily. To reduce potential interference, we did not install infrared cameras at each nest. We visited nests regularly (every 1–7 days) to examine basic nesting parameters, such as clutch size, nest success and, when possible, causes of nest failure.

Referring to methods modified from the BBIRD protocols (Martin et al. 1997) and other studies of bird-habitat relationships in general, we measured a total of 13 variables (Additional file 1: Table S1) at nest sites and random sites. We also recorded the plant species used for the nest site. Each nest site was paired with one random site located at 50 m in a stochastic direction (generated by a group of number from 1 to 8, indicating north, northeast, east, southeast, south, southwest, west and northwest, respectively). Random sites were searched to confirm the absence of an Emei Shan Liocichla nest. Our plots were 10 m × 10 m in size. Following Bulluck and Buehler (2008), we used an ocular tube (James and Shugart 1970) to determine the percent cover of trees, shrubs, bamboo and herbs. Since lianas parasitize other plants, it is difficult to determine liana cover and hence we measured liana abundance qualitatively using visual methods. We defined distance to forest edge or gap as the distance from the plot center to the nearest forest edge or gap and distance to water as the distance from the plot center to the nearest water source (both standing and running water). The detailed measurements for all variables are described in Additional file 1: Table S1. We recorded all measurements only after each nest had failed or succeeded, in order to minimize human disturbance.

Analyses

We used the nest survival analysis in Program MARK to estimate daily nest survival rates (DSR) (Dinsmore et al. 2002). Nest success was calculated using the Mayfield method (Mayfield 1961, 1975). Nests were considered successful if at least one nestling fledged. Nest predation was determined by both video data and from nest remains (e.g. eggshell fragments and body remains).

We used the Kolmogorov–Smirnov *Z*-test to examine all variables for normality. For normally distributed variables, we used the paired samples *t* test to test the differences of the variables between nest sites and random sites. Conversely, the Wilcoxon rank sum test was used to test for the differences of abnormally distributed variables. The variables with significant differences ($p < 0.05$) were retained. Then, we used Spearman's correlation test. For paired variables with strong correlations ($|r_s| \geq 0.6$), we removed the ones with less ecological significance (LaHaye and Gutiérrez 1999). We used Binary Logistic Regression (Forward: conditional) to determine the most important variables affecting nest-site selection of the Emei Shan Liocichla. We applied the Hosmer and Lemeshow Test (Hosmer and Lemeshow 1989) and the percentage of predicted correct classification (Augustin et al. 1996) to test the model to see if it fitted the data. Finally, we tested the differences of the variables between successful and failed nests using the independent sample *t*-test for the normally distributed variables or the Mann–Whitney *U*-test for those variables abnormally distributed, based on the normality of the data. All analyses were carried out using SPSS 19.0. Data are presented as mean ± SE.

Results

Nest success and nest predators

A total of 56 nests were found (2009: $n = 11$; 2010: 15; 2011: 7; 2013: 8; 2014: 15). Thirty-nine nests were found in bamboo (i.e. *C. szechuanensis*), sixteen in small shrubs (including roses) and one in lianas. We determined the fate of 49 nests. Among these, 18 (36.7 %) nests were successful, while 31 (63.3 %) nests failed. The DSR for all nests that contained at least one egg was 0.9564 ± 0.0091 (95 % CI 0.9346–0.9711) ($n = 40$) and the total nest success rate was 27.5 %. Nest success fluctuated from 14.7 to 35.5 % during our years of observation (Table 1).

Factors affecting nest success were nest predation (51.6 %, $n = 16$), abandonment (25.8 %, $n = 8$) and inclement weather (3.2 %, $n = 1$), but the reason for the lack of success of 19.4 % of nests ($n = 6$) could not be determined. The rate of nest predation increased as breeding proceeded (egg-laying period, $n = 1$; incubation period, $n = 5$; nestling period, $n = 10$).

We installed a total of 20 infrared cameras. Four categories of predators were identified in 10 nest predation events (eight from video records of infrared cameras and two from direct observation when we visited the nests) during the five breeding seasons. The predators were squirrels ($n = 5$), snakes ($n = 3$), raptors ($n = 1$) and wasps ($n = 1$).

Nest-site selection

Emei Shan Liocichlas prefer to nest at sites close to forest edges or gaps in the forest, with few trees, more shrubs, greater bamboo cover, more herbs and abundant lianas (Table 2). The best Logistic Regression model indicated that tree cover, bamboo cover, liana abundance and distance to forest edge or gap were the most important variables affecting nest-site selection by the Emei Shan Liocichla (Table 3).

The Hosmer and Lemeshow Test shows that the goodness-of-fit of the final model is good ($\chi^2 = 7.039$, $df = 8$, $p = 0.532$). The percentages of predicted correct classification for nest sites was 94.6, for random sites 91.1 and for overall 92.9 (the best cut value was 0.6).

Table 1 The daily nest survival rates (DSR) and nest successes of the Emei Shan Liocichla for nests that contained at least one egg at Laojunshan National Nature Reserve, Sichuan, China

Years	DSR	95 % CI	Nest success (%)	*n*
2009	0.9591 ± 0.0201	0.8959–0.9846	29.8	7
2010	0.9527 ± 0.0267	0.8631–0.9847	24.5	7
2011	0.9600 ± 0.0278	0.8534–0.9900	30.6	4
2013	0.9361 ± 0.0253	0.8647–0.9711	14.7	8
2014	0.9649 ± 0.0131	0.9281–0.9832	35.5	14

Successful versus failed nests

There were no significant differences in any of the variables between successful and failed nests (Table 4), suggesting that the nest-site-selection cues preferred by the Emei Shan Liocichla seemed not to be positively associated with nest success.

Discussion

Nest success

Our results indicated that the total nest success of the Emei Shan Liocichla was low (27.5 %). Similarly lower nest successes have been reported in many species of the family Timaliidae in southern China, such as the Fulvous Parrotbill (*Paradoxornis fulvifrons*) (18.18 %, Hu et al. 2014), the Red-billed Leiothrix (*Leiothrix lutea*) (22.95 %, Ma et al. 2010) and the Golden Parrotbill (*Paradoxornis verreauxi*) (38.89 %, Yang et al. 2011). In these cases, nest predation or nest desertion accounted for most nest failures. In our study, nest predation was the main factor affecting nest success of the Emei Shan Liocichla. Besides, human disturbance (mainly by tourists) may be another important factor affecting success, which prompted nest desertion as the Liocichla seemed to prefer nest sites near trails (we are collecting more related evidence).

Our findings also raise an interesting phenomenon regarding the yearly fluctuation (from 14.7 to 35.5 %) of nest success of our species (Table 1). Whether this was associated with changes of predator densities and therefore resulted in population fluctuation in the number of Emei Shan Liocichlas needs further study.

Nest-site selection

For most bird species, nest-site selection is largely based on small-scale vegetation structure (Yang et al. 2000). Vegetation structures may provide escape cover against predators, suitable nesting sites and/or food sources for birds (Feinsinger et al. 1988; Lima 1993). Bamboo would appear to be the key nesting plant for the Emei Shan Liocichla at Laojunshan, given that most nests (~70 %) were found in bamboo (*C. szechuanensis*). Bamboo cover (i.e. dense bamboo leaves) may be selected by this species as a potential escape cover, which could be safer compared to other types of understory cover (Reid et al. 2004).

Studies have shown that the Emei Shan Liocichla is a typical forest edge or gap bird (Fu et al. 2011, 2013). Our results confirmed this again (Table 2). Generally, there are fewer trees at the forest edge or gap. Lower tree cover is conducive to the growth of bamboo, which

Table 2 Comparisons of variables between nest sites and random sites of the Emei Shan Liocichla at Laojunshan National Nature Reserve, Sichuan, China

Variables[a]	Nest sites ($n = 56$)	Random sites ($n = 56$)	t value and significance	Z value and significance
AL (m)	1693.9 ± 22.0	1691.5 ± 22.2		−0.339 ns
SA	1.9 ± 0.1	1.9 ± 0.1		−0.775 ns
TH (m)	3.4 ± 0.6	10.3 ± 0.6		−5.951***
TC (%)	9.1 ± 2.0	45.1 ± 2.7		−6.174***
SH (m)	3.1 ± 0.1	3.7 ± 0.1	−4.981***	
SC (%)	40.9 ± 3.7	33.0 ± 2.8		−2.322*
BH (cm)	199.0 ± 6.9	207.0 ± 2.9		−0.106 ns
BC (%)	58.8 ± 4.7	46.5 ± 4.0	3.092**	
HH (cm)	27.4 ± 3.2	17.5 ± 1.4		−3.055**
HC (%)	15.3 ± 2.0	10.8 ± 2.0		−2.536*
LA	2.8 ± 0.1	2.2 ± 0.1		−4.306***
DF (m)	14.9 ± 1.1	24.4 ± 1.7		−4.303***
DW (m)	26.8 ± 2.5	28.3 ± 2.8		−0.380 ns

[a] *AL* altitude, *SA* slope aspect, *TH* mean height of trees, *TC* tree cover, *SH* mean height of shrubs, *SC* shrub cover, *BH* mean height of bamboo, *BC* bamboo cover, *HH* mean height of herb, *HC* herb cover, *LA* liana abundance, *DF* distance to forest edge or gap, *DW* distance to water

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. *ns* not significant

Table 3 The variables in the best model of Logistic Regression of nest-site selection by the Emei Shan Liocichla at Laojunshan National Nature Reserve, Sichuan, China

Variables	B	SE	Wald statistics	df	p value
TC	−0.110	0.022	25.962	1	<0.001
BC	0.025	0.012	3.894	1	0.048
DF	−0.093	0.035	7.210	1	0.007
LA	2.204	0.626	12.406	1	<0.001
Constant	−2.243	1.789	1.572	1	0.210

TC tree cover, *BC* bamboo cover, *DF* distance to forest edge or gap, *LA* liana abundance, *B* partial regression coefficient

may be one important reason why this species prefers habitats close to the forest edge or gap. As well, the Emei Shan Liocichla shows an apparent preference for shrubs, lianas and herbs, which are important characteristic plants of the forest edge or gap in our study site. For this bird, shrubs with dense foliage, such as *Eurya* sp. and *Rubus* sp., are its potential nesting plants. As well as providing part of their nest material, the abundant leaves of lianas and herbs may, to a large extent, increase the concealment of their nest sites. The mean concealments above and around their nests were >90 % (Fu et al. 2011). We conclude that the Emei Shan Liocichla tends to select nest sites with good concealment, which agrees with the nest-concealment hypothesis (Martin 1993b).

Successful versus failed nests

A prevalent theory suggests that habitat preferences of animals should be adaptive, such that fitness is more prevalent in preferred habitats than elsewhere (Hildén 1965; Southwood 1977; Martin 1998). If nest-site selection were adaptive, the attributes of successful and failed nests would differ (Cancellieri and Murphy 2014). However, our results were inconsistent with this hypothesis, although it is possible that a larger sample size would be required to test this fully. A number of studies of cup-nesting passerines have also shown a lack of association between nesting success and habitat attributes (Holway 1991; Filliater et al. 1994; Wilson and Cooper 1998). Nest predation has been suggested as one of the most important factors affecting nest success (Ricklefs 1969; Martin 1988). For example, Lack (1954) estimated that 75 % of all eggs and nestlings lost from open cup nests are taken by predators. Filliater et al. (1994) argued that adaptive nest-site selection is impossible when intense predator pressure reduces the probability of success to little more than a stochastic event.

In our study system, nest predation was the main cause of nest failure, with various nest predators. Among them, squirrels and raptors forage mainly by visual cues, while snakes largely use infrared heat-sensing and wasps chemical information. Differences in search strategies among predators may constrain the ability of Dusky Flycatchers (*Empidonax oberholseri*) to optimize nest-site selection (Liebezeit and George 2002), which may also characterize the Emei Shan Liocichlas.

Table 4 Comparisons of variables between successful and failed nests of the Emei Shan Liocichla at Laojunshan National Nature Reserve, Sichuan, China

Variables	Successful nests ($n = 18$)	Failed nests ($n = 31$)	t value and significance	Z value and significance
AL (m)	1711.2 ± 37.3	1682.4 ± 30.9		−0.902 ns
SA	1.8 ± 0.2	1.9 ± 0.2		−0.274 ns
TH (m)	3.0 ± 1.1	3.4 ± 0.8		−0.216 ns
TC (%)	11.9 ± 4.6	6.4 ± 2.2		−0.192 ns
SH (m)	3.1 ± 0.2	3.0 ± 0.1	0.479 ns	
SC (%)	44.7 ± 7.1	39.1 ± 4.8	0.678 ns	
BH (cm)	195.3 ± 12.7	198.0 ± 10.0		−0.437 ns
BC (%)	58.0 ± 9.3	57.4 ± 6.1	0.054 ns	
HH (cm)	21.6 ± 3.8	32.7 ± 5.1		−1.401 ns
HC (%)	11.5 ± 3.1	19.2 ± 2.8	−1.744 ns	
LA	2.8 ± 0.1	2.8 ± 0.1		−0.526 ns
DF (m)	14.1 ± 1.3	14.8 ± 1.6	−0.322 ns	
DW (m)	22.8 ± 3.5	25.6 ± 3.2	−0.561 ns	

AL altitude, *SA* slope aspect, *TH* mean height of trees, *TC* tree cover, *SH* mean height of shrubs, *SC* shrub cover, *BH* mean height of bamboo, *BC* bamboo cover, *HH* mean height of herb, *HC* herb cover, *LA* liana abundance, *DF* distance to forest edge or gap, *DW* distance to water

ns not significant

Conclusions

Our study suggests that nest predation by various predators was the primary reason for nest failure of the Emei Shan Liocichla. This bird species preferred forest edges or gaps as its nesting habitat, and usually hided their nests in dense bamboos and some small shrubs with abundant foliage to avoid nest predation. But the nest-site-selection cues preferred by the Emei Shan Liocichla seemed to be not positively associated with nest success. Intense predator pressure may constrain the ability of this species to optimize nest-site selection.

Conservation implications

The Emei Shan Liocichla is suspected to be declining at a moderate rate, in line with rates of habitat loss and degradation within the range of this species (BirdLife International 2016). Currently, it is most important to protect their remaining habitats and identify the precise habitat requirements of this species. Our results suggest that the Emei Shan Liocichla prefers forest edges or gaps as its habitat, while bamboo may be the key plant of its nesting habitat. Consequently, reducing forest-edge development and protecting bamboo (especially *C. szechuanensis*) should be effective for the conservation of the Liocichla.

Additional file

Additional file 1: Table S1. Variables and measurements for nest-site selection by the Emei Shan Liocichla at Laojunshan National Nature Reserve, Sichuan, China.

Authors' contributions

YF, SD and ZZ conceived and designed the project. YF and BC performed the project. YF, SD and ZZ analyzed the data and drafted the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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