RESEARCH NOTE

Threatened songbird *Liocichla omeiensis* impacted by climate-induced outbreak of the moth *Pantana phyllostachysae*: An example of the impact of climate change through multi-species interactions

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Abstract
In this study, we reported a case of insect-plant-bird interactions under climate warming. With a succession of warmer winters from 2013 to 2015, successive outbreaks of the moth *Pantana phyllostachysae*, a common defoliator for most bamboo species, occurred in the Wawushan Nature Reserve of Southwest China, leading to a rapid altitudinal range expansion from 1650 to 2050 m in *P. phyllostachysae*. The bamboo *Chimonobambusa szechuanensis* that is largely distributed at moderate altitudes consequently suffered much loss. Accumulated infested area of *C. szechuanensis* within the reserve during the 3 years covered ~90% of the suitable breeding habitats of Emei Shan *Liocichla Liocichla omeiensis*, a threatened songbird preferring to nest in the bamboo, which led to diversified nesting-plant selection and a significant reduction in nesting success of the babbler. Our findings provide new evidence of the plasticity of avian breeding behavior, and of the impact of climate change on ecological communities through multi-species interactions. The study has important conservation implications.

KEYWORDS
abnormal climate, cascading ecological consequences, conservation implications, multi-species interactions

1 INTRODUCTION

There is growing evidence of the profound impacts of climate change on global biodiversity (Nunez et al., 2019).

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The multiple components of climate change are anticipated to affect all the levels of biodiversity, from organisms to biomes (Parmesan, 2006). At the community level, the various effects on populations are likely to modify the “web of interactions” (Gilman et al., 2010; Walther, 2010). Impacts of climate change on individual species are increasingly well documented, but lacking understanding.
of how these effects propagate through ecological communities (Schleunig et al., 2016).

Birds are among the most widely studied organisms on earth, and represent an important indicator group for learning about the effects of climate change (Gregory et al., 2009; Şekercioglu et al., 2012). Under climate warming, the abnormal outbreak of insects is one of major natural disturbance events that affect communities of forest birds, either directly by affecting the food supply or indirectly by changing the vegetation composition of forest canopies (Drever et al., 2018). Although progress in recent years has been rapid in many areas, there remain vast gaps in our knowledge of climate change effects on birds (Martin, 2011). Here, we reported an abnormal climate event affecting breeding behavior and nesting success of the Emei Shan Liocichla Liocichla omeiensis through multi-species interactions in Wawushan Nature Reserve of Southwest China.

2 | METHODS

2.1 | Study site

The study was carried out at the Wawushan Nature Reserve (29°25′–29°34′ N, 102°49′–103°00′ E; altitude 1023–3522 m), Sichuan province, China. The climate is temperate with annual average precipitation 2000 mm and relative humidity of 85%–90%. The annual average temperature is 10°C–14°C. The main vegetation type is evergreen broadleaf forest. The bamboo Chimonobambusa szechuanensis is abundant at moderate altitudes from 1600 to 2400 m in the reserve. There are plenty of well-developed non-native coniferous forests at lower elevations (<1600 m). It is one of the most important sites for a Chinese endemic songbird, the Emei Shan Liocichla L. omeiensis, listed as Vulnerable by the IUCN (https://www.iucnredlist.org/) because of a small, declining population and fragmented range. It is difficult to see the liocichla in the field due to its secretive nature, and it prefers to nest in the bamboo C. szechuanensis as thick bamboo leaves provide cover to reduce nest predation by predators such as the Pallas's squirrel Callosciurus erythraeus and Eurasian jay Garrulus glandarius (Fu et al., 2011, 2016). A survey shows that the breeding population density of Emei Shan Liocichla in 2010 was 2.44 ± 1.02 calling males/km², and its nesting season is from late April to August in the reserve (Fu, 2011).

2.2 | Extreme climate and the moth Pantana phyllostachysae outbreak

A succession of warmer winters from 2013 to 2015 was recorded in Hongya County, Sichuan Province where the Wawushan Nature Reserve is located. Compared with the same period of historical data, the average temperature in January (the coldest month of year in Hongya) in the 3 years increased by 0.6°C, 1.6°C, and 2.1°C, respectively (data from the Hongya Meteorological Bureau).

The moth Pantana phyllostachysae (Order: Lepidoptera; Family: Lymantriidae), a common defoliator for most bamboo species (Liang et al., 2004), was found propagating at low altitudes adjacent to the reserve in the spring of 2013, and then spread rapidly within the reserve in the following 2 years. One of important reasons is that the reserve has abundant food resources (i.e., the bamboo C. szechuanensis) for P. phyllostachysae. Infestation by P. phyllostachysae caterpillars causes bamboo leaf loss, restricted growth and even death (Liang et al., 2004). The moth P. phyllostachysae produces three generations of larvae a year in Southwest China, and its main harmful seasons are in spring (mainly from early March to late April), summer (from early June to late July) and autumn (from September to October) when the larvae feed on much bamboo leaves (Lin & Su, 2017). This outbreak ended in 2016.

2.3 | Data collection

We recorded its altitudinal range expansion using a portable GPS (Garmin) during the outbreaks of the moth P. phyllostachysae in Wawushan Nature Reserve. As most (>80%) of Emei Shan liocichlas nest in the bamboo C. szechuanensis (Fu, 2011), to assess the impacts of this event on the liocichla, we made comparisons of data on breeding behavior and nesting success of the liocichla before (in 2010) and after (in 2015) the outbreak of P. phyllostachysae.

We found nests of the Emei Shan liocichla by observing behaviors and tracking breeding pairs as well as systematic searching (Martin & Geupel, 1993) along fixed transects (10 m wide, each transect means 2 km long) at the altitude ranges from 1600 to 2000 m in Augusts of 2010 and 2015. Following Hoover and Brittingham (1998), a modification of white cover board (20 × 20 cm) with 100 grids (2 × 2 cm) was used to estimate nest concealment. The cover board was placed directly on the east, south, west, north facing, top, and bottom sides of each nest, respectively. We took pictures with digital cameras from each direction at a lateral distance of 2 m from the cover board at the height of the nest, from 1 m above, and from ground level beneath the nest, and then recorded the number of grids completely visible as an index of nest exposure both horizontally and vertically. Nest predation was determined by both checking whether the nest was intact and from nest remains (e.g., eggshell fragments and body remains).
2.4 Data analysis

Nesting success was defined as the proportion of successful nests of Emei Shan Liocichla. Nests were considered successful if at least one nestling fledged. We used independent samples T-test to test the differences of nest concealment between years as the data were normally distributed. In addition, a two-tailed Fisher's exact test was used in the analysis of nesting-plant selection of Emei Shan Liocichla. All analyses were conducted using SPSS 19.0. Data are presented as mean ± SE.

3 RESULTS

From 2013 to 2015, a succession of outbreaks of the moth Pantana phyllostachysae occurred in the Wawushan Nature Reserve, leading to a rapid altitudinal range expansion averaging 200 m per year (the upper limits were 1650 m in 2013, 1800 m in 2014, and 2050 m in 2015, respectively) in P. phyllostachysae. The abundance of P. phyllostachysae caterpillars ranged from 15 to 100 per bamboo. As the bamboo C. szechuanensis (Emei Shan Liocichla’s favorite nesting plant) is dominant at this altitude range, accumulated infested area of C. szechuanensis during the 3 years covered ~90% of the suitable breeding habitats of Emei Shan Liocichla within the reserve.

A total of seven nests were found within three transects (totally 6 km long) in 2010 when no P. phyllostachysae caterpillars were found to propagate in the reserve. They were all built in C. szechuanensis, and nesting success was 42.9% (i.e., three successful nests). By contrast, no Emei Shan Liocichla nests were found within the same three transects where there was a large-scale outbreak of P. phyllostachysae in 2015. We expanded the survey area and increased the number of transects from 3 to 9 (totally 18 km long), and five nests were eventually found. They were built in C. szechuanensis (n = 2), small shrubs (n = 2), and roses (Rosa sp.) (n = 1), respectively, suggesting that Emei Shan Liocichlas were less likely to select bamboo for nesting as usual in 2015 (P = .0455). The concealments above and around nests of 2015 (above: 85.0 ± 2.9%; around: 82.6 ± 1.7%. n = 5) were significantly lower than those of 2010 (above: 98.6 ± 1.4%; around: 95.4 ± 1.6%. n = 7) (P < .01), while there was no obvious difference in the concealments below nests between the 2 years. The concealments of the two nests of 2015 built in the bamboo (above: 85.0 ± 5.0%; around: 83.8 ± 3.8%. n = 2) were also significantly lower than those of 2010 (P < .05). All the five nests found in 2015 failed due to nest predation.

4 DISCUSSION

Many insect species in temperate regions are believed to be limited in their distribution by low temperature (Crozier, 2004; Ungerer et al., 1999). It is clear that increasing temperature contributes to altitudinal and/or latitudinal range expansions of forest pests, such as Thaumetopoea pityocampa, Operophtera brumata, and Lymantria dispar (Chen & Ma, 2010). Studies show that climate factors play a major role in regulating population dynamics of P. phyllostachysae (Chen & Wang, 1993), and warm winter is conducive to the reproduction of P. phyllostachysae (Liang et al., 2004; Luo, 2006), thus the warmer winters from 2013 to 2015 may be the main driver of the succession of outbreaks of P. phyllostachysae in our study site. According to meteorological records, an extreme cold wave hit most areas of Sichuan including the Wawushan Nature Reserve from January 19th to 25th, 2016 when the daily minimum temperature of 138 counties decreased by 8°C–16°C (Sichuan Climate Center, 2016). This cold weather significantly prolonged

FIGURE 1 The normally growing bamboo Chimonobambusa szechuanensis (left), the infested bamboo (middle), and the moth Pantana phyllostachysae (right)
freezing duration of the reserve, which might consequently kill the overwintering eggs and larvae of the moth *P. phyllostachysae* in the reserve. After that, there were no abnormal warmer winters at our study site so far, and the moth *P. phyllostachysae* did not spread there, either. Therefore, the view that warmer winters may drive the moth *P. phyllostachysae* outbreaks in addition, it is notable that, in our study, the moth *P. phyllostachysae* exhibited strong ability of altitudinal range expansion (from 1650 to 2050 m), which significantly exceeded the upper limit (~1600 m) of the known altitudinal distribution of the species (Liang et al., 2004). This will be of great significance to the early warning of the pest under climate warming. Battisti et al. (2010) reported a similar event of rapid altitudinal range expansion in the pine processionary moth *Thaumetopoea pityocampa* produced by the 2003 climate anomaly, suggesting the importance of extreme climatic events in the range formation of phytophagous insects.

For many species, the primary impact of climate change may be mediated through effects on synchrony with species’ food and habitat requirements (Bellard et al., 2012). *P. phyllostachysae* caterpillars are densely covered with long venomous hairs and can secrete venom. We are not sure whether Emei Shan Liocichla could feed on the moth or its larvae. At our study site, the bamboo *C. szechuanensis* suffered much loss due to the outbreaks of *P. phyllostachysae*, resulting in severe defoliation and a small number of deaths (Figure 1), which meant that the Emei Shan Liocichla lost its most suitable nesting habitat as the babbler prefers to hide its nest in dense bamboo to increase nest concealment and consequently reduce the risk of nest predation (Fu et al., 2016). As a result, many of the liocichlas might be forced to leave in search of new suitable habitat, which was consistent with the report that there was a significant reduction in bird species associated with closed-canopy forests during the outbreak year(s) of gypsy moth (*Lymantria dispar*) (Gale et al., 2001). That was the most likely reason why the nest density of the liocichla in 2015 declined sharply. The remaining individuals had to use degraded bamboo or other plants for nesting, such as small shrubs and rose bushes. Compared with the nests of 2010, the ones of 2015 had lower concealments above and around nests, which may partially account for the nest failures of 2015 because their predators (e.g., squirrels and jays) could find these relatively exposed nests more easily. To our knowledge, the reserve had been under closed management from 2012 to 2018, so there was no interference from human activities that may potentially affect the population dynamics and nesting success of Emei Shan Liocichla. A recent survey showed that the breeding population density of Emei Shan Liocichlas in the reserve was $2.17 \pm 0.80$ calling males/km$^2$ in 2018 (Unpublished data from the first author), approaching the pre-outbreak density of 2010 ($2.44 \pm 1.02$ calling males/km$^2$; Fu, 2011), suggesting the effects of local outbreaks of the moth *P. phyllostachysae* on the liocichla are likely to be short-term.

In conclusion, our findings provide new evidence of the plasticity of avian breeding behavior, and of the impact of climate change on ecological communities through multi-species interactions (Walther, 2010), which may play an important role for modulating the composition and population dynamics in ecological communities, and remind forestry managers and conservationists to pay attention to profound effects of extreme climate events on forest ecosystems and take appropriate actions accordingly.

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**CONFLICT OF INTEREST**

The authors declare no potential conflict of interests.

**AUTHOR CONTRIBUTIONS**

Yiqiang Fu, Simon D. Dowell, and Zhengwang Zhang conceived the study. Yiqiang Fu, Yuanyuan Xu, and ShuFang Wang collected the data. Yuanyuan Xu and ShuFang Wang analyzed the data. All authors contributed to manuscript preparation.

**DATA AVAILABILITY STATEMENT**

All datasets used in this study are included in the main text.

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