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Short Communication

Breeding Variation in a Reintroduced Crested Ibis *Nipponia nippon* Population in Central China

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Authors' Contributions
DL and JL conceived and designed the experiments. DL executed the experimental work, analyzed the data and wrote the article. GZ, CW and BQ also performed the experiments.

Key words
Breeding variation, Colonial nesting, Crested ibis, Mating system flexibility, Reintroduction.

ABSTRACT

The crested ibis *Nipponia nippon* formerly occurred throughout East Asia, but since 1981 its unique population has been confined to a narrow band in transborder area of Yangxian, Chenggu and Xixiang County of Shaanxi Province, Central China, on the south slope of the Qinling Mountains. During 2004-2005, 23 crested ibises were experimentally reintroduced to an isolated basin in Qinling Mountains, where they and their offspring exhibited breeding variation never observed in wild population in the following 9 breeding seasons. Crested ibis has been considered a monogamous species, and breeding pair is solitary and territorial. However, 3.4% of breeding females exhibited polyandry and 43.1% of nests were observed colonial in single tree in the reintroduced population, probably due to male-biased sex ratio and better nesting conditions. First nest failure in reintroduced population occurred much earlier than that in wild, which resulted in significantly higher probability of re-nesting. The phenotypic plasticity in crested ibis may play important role in future reintroduction of this critically endangered species under a changing environment.

The crested ibis (*Nipponia nippon*), listed as endangered in the IUCN Red List since 2000, was formerly widespread in Asia (BirdLife International, 2016). Habitat degradation and over-hunting of the species led to its rapid decline and subsequent extinction of the population from Russia, Korean Peninsula and Japan during the twentieth century (BirdLife International, 2016; Shi and Cao, 2001). In May 1981, a remnant population of seven birds was discovered in the Qinling Mountains of Central China (Liu, 1981). Since then intensive conservation efforts have been made to restore the population. As a result, the wild population of crested ibis increased to over 1000 individuals, with another 670 in captivity (Liu *et al*., 2014; Wang *et al*., 2014).

The reproductive biology of the crested ibis has been well studied and documented since 1980s (Shi *et al*., 1989; Zhai *et al*., 2001; Yu *et al*., 2006, 2007). Crested ibis is socially monogamous, with quite high mate fidelity and nest site fidelity between years (Lu *et al*., 1997; Shi and Cao, 2001). The birds build solitary nest on large trees near rice paddies and human settlements, showing territoriality in the breeding season (Shi *et al*., 1989; Shi and Cao, 2001). Nesting altitudes range from 500 to 1200 m, but no significant variation is found in clutch size and breeding success across altitudinal zones (Zhai *et al*., 2001; Yu *et al*., 2006). Both male and female contribute to nesting, hatching and feeding chicks (Shi *et al*., 1989; Ding, 2004), and the breeding success is quite high in nidicolous birds due to stability of pair maintenance and human protection (Yu *et al*., 2006).

To reduce the risk of extinction inherent in a species confined to limited mountain area vulnerable to catastrophes such as epidemic diseases, climatic disasters and feeding ground pollution, reintroduction of crested ibis has been planned to establish a second population in its historical range since 2000 (Zheng, 2000). To make technical preparation, an experimental reintroduction was conducted during 2004-2005, and 23 (12♂ and 11♀) captive-bred crested ibises were released after acclimation at Huayang, 30 km from the main distribution area of wild population (Liu *et al*., 2005, 2008). During 2006-2014, breeding performance of the reintroduced and wild crested ibis population was monitored. Unexpected reproductive traits of the reintroduced population were revealed that are

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described in this paper.

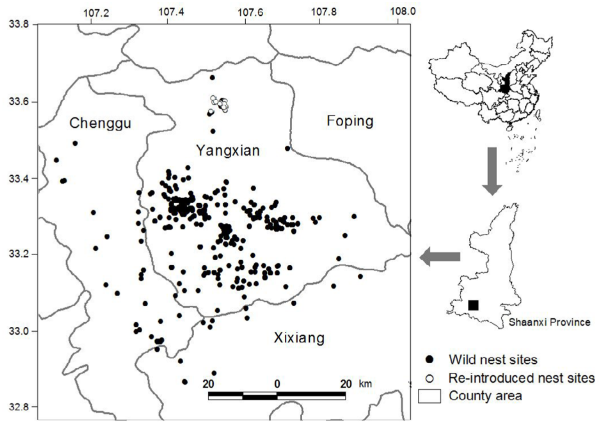

Fig. 1. Map of the study area and the nest sites of wild and reintroduced crested ibis during 2006-2014.

Materials and methods

The study was conducted in the transborder area of Yangxian, Chenggu and Xixiang County (32°30′-33°40′N, 107°05′-107°50E) of Shaanxi Province, Central China, on the south slope of the Qinling Mountains (Fig. 1). The breeding areas of wild crested ibis, ranging from 500 to 1200 m in altitude, are dominated by deciduous broadleaved forests and mixed broadleaf-conifer forests, with rice paddies, reservoirs, rivers, and farmlands in valleys. The experimental reintroduction of crested ibis was performed at Huayang town (33°34′ N, 107°31′ E; elevation averages 1100 m), which is an isolated basin on the southern slope of Qinling Mountains, 30 km from the main distribution area of wild population and supporting two pairs of wild crested ibises.

For breeding surveys all of the 23 released birds were given unique numbered plastic bands, and 11 of them were collared with 11-g radio transmitters (type RI-2D; Holohil Systems Ltd., Canada; Liu *et al*., 2005, 2008). During 2006-2014, 65 nests of released crested ibis and their offsprings were located either by homing on transmitter signals using receivers and handheld antennas (Wildlife Materials International, Inc., USA; Mech and Barber, 2002), or by investigation of breeding pairs' distinct territorial displays including copulation, vocalizing and flying around nest sites (Shi *et al*., 1989; Shi and Cao, 2001). Regular observations were conducted from an elevated hide or from high ground near the nest, to determine the clutch size, brood size and number of chicks fledging from each nest. Nestlings, if accessible, were color banded at 20-25 days of age.

For wild population, most of nestlings have been color marked since 1987 (Lu *et al*., 1997), which enables us to identify individuals. Comparisons to reintroduced population are based on data of wild population collected through the same methods and during the same period. Statistics were reported as mean ± SD.

Table I.- Reproductive traits of reintroduced and wild crested ibis.

Trait	Reintroduced	Wild
Clutch size	2.56 ± 0.67 (41)	2.73 ± 0.61 (323)
Breeding success	69.4 ± 23.7% (37)	69.0 ± 22.1% (291)
Productivity	1.81 ± 0.61 (48)	1.87 ± 0.64 (1031)
Failed first nest	0.19 (59)	0.17 (1248)
Re-nesting*	0.36 (11)	0.12 (217)
Colonial nesting*	43.1% (65)	0 (1280)
Polyandry*	3.4% (59)	0 (1248)

*Significant difference between the reintroduced and wild populations. Failed first nest, the probability of failure for the first nest; re-nesting, the probability of re-nesting after nest failure; colonial nesting, the percentage of nests observed in colony; polyandry, the percentage of breeding females exhibited polyandry. Sample size is presented in parentheses.

Results

During 2006-2014, no significant differences of Clutch sizes (Independent-sample T test, t = 1.660, P = 0.098), breeding success (t = 0.106, P = 0.916) and productivity (t = 0.645, P = 0.519) were observed between the reintroduced and wild populations (Table I). 43.1% of nests were observed colonial in single tree in the reintroduced population (Table I), while this occurrence was not recorded in wild population. The colonial nesting trees had significantly larger diameter at breast height (DBH) than solitary nesting trees (t = 8.229, P < 0.001; Fig. 2). The number of colonial nests averaged 3.1 ± 0.9 (n = 9, range 2-5) per tree, with an average distance of 3.5 ± 1.3 m (n = 26, range 2-6 m).

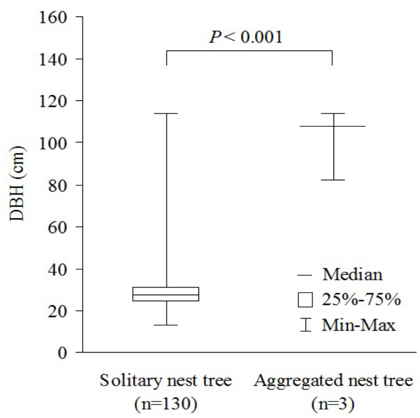

Fig. 2. Diameter at breast height (DBH) of solitary and colonial nest trees in crested ibis.

The probability of failure of the first nest was similar in the reintroduced and wild populations (Binomial test, $P = 0.421$, Table I); 72.8% of nest failures in the reintroduced population occurred during March and April, while 36.0% in the wild population (Fig. 3). The probability of re-nesting after nest failure in the reintroduced population was 0.36, significantly higher than that in the wild population (Binomial test, $P = 0.034$, Table I).

Wild crested ibis showed monogamous behavior. Both the male and female wild crested ibis contributed to nesting, hatching and feeding chicks. By contrast, two females (3.4%, n = 59) were observed to exhibit polyandry in the reintroduced population (Table I). In both cases, the female deserted her first clutch immediately after egg laying, and formed pair bond with another male to produce a new clutch. The male-only care for the first clutch or brood caused nesting failure in both cases.

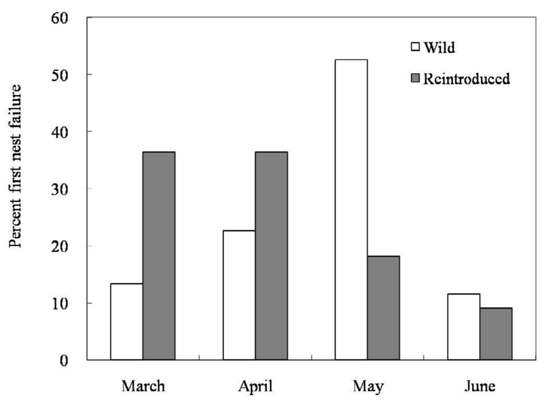

Fig. 3. Percentage of first nest failure in wild and reintroduced crested ibis population by month during 2006-2014.

Discussion

The reintroduced crested ibis exhibited widespread colonial nesting never observed in the wild population. Archibald and Lantis (1979) once speculated that crested ibis probably nested in colony in Central China before 1950s when large trees were available, whereas it was solitary in Siberia and Japan due to scarcity of food. The nationwide logging of mature trees in China during late 1950s resulted in dramatic population decline (BirdLife International, 2001; Shi and Cao, 2001), and the last remnant population survived in remote Qinling Mountains where only a small amounts of nest trees and paddy fields were available. The crested ibis exhibited territorial in the breeding season, and each pair occupied a territory of about 1-2 km^2 (Shi and Cao, 2001). As the population increased, the breeding region of crested ibis gradually expanded to lower mountains, where the nests were getting concentrated and were as close as 10 m due to high quality of food supply (Liu *et al*., 2003). Moreover, the species was recorded to colonially nest with Little Egret (*Egretta garzetta*) and Chinese Pond Heron (*Ardeola bacchus*) in single *Quercus variabilis*, a relative large nest tree species available (Yu *et al*., 2006). Based on this information, our result indicated that a reasonable proximate explanation of the colonial nesting is the availability of large nest trees in Huayang basin with abundant food.

Re-nesting is an important breeding strategy used by birds to compensate for the nest loss. Re-nesting propensity is affected by many factors including seasonal timing (Arnold *et al*., 2010; Gates *et al*., 2013). In our study, 23% of unsuccessful pairs re-nested if their first nests failed before April but only 5% re-nested after May, showing remarkable temporal correlation. Thus, significantly different timing in first nest failure contributed to the different possibility of re-nesting between the wild and reintroduced populations. In the wild population, death of altricial chicks due to shortage of food, predation, parasites and adverse weather conditions in early stage is the primary factor affecting breeding success (Ding, 2004; Yu *et al*., 2006). As a result, more than half of nest failures occurred at nestling stage after May. In the reintroduced population, however, nest failure was mainly attributed to egg loss caused by parent treading, and occurred much earlier, which raised the possibility of initiating a re-nest.

Adult sex ratio plays a central role in mating systems, and females are more polygamous when males outnumber females (Liker *et al*., 2013, 2014; Maqsood *et al*., 2019). Our observation of polyandry in reintroduced crested ibis population supports this theory. Female crested ibis shows significantly greater dispersal distance than male both in the wild and reintroduced populations (Yu *et al*., 2010; Ministry of Environment of Japan, 2014), which may have significant impact on adult sex ratio of small isolated population. In our reintroduction, 13 of 23 released birds inhabited in Huayang basin of the Qinling Mountain in spring of 2006, of which five were female. As a result, mating system flexibility occurred in this isolated population with male-biased sex ratio, which acted as a buffer mechanism to reduce the impact of environmental and demographic noise in the small population (Rossmanith *et al*., 2006). Nesting failure in polyandrous females indicated that biparental care of nestling stages is probably necessary for successful breeding in crested ibis.

Thus, the reintroduced crested ibis showed phenotypic plasticity which is the ability of one genotype to produce more than one phenotype when exposed to different environments (Price *et al*., 2003). The phenotypic plasticity may play an important role in the restoration of this endangered species, especially under a changing environment in China. Currently, reintroduction activities of crested ibis are being conducted at several sites in China and Japan, which provide opportunities to understand the degree and cost of adaptive phenotypic plasticity.

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Statement of conflict of interest

The authors declare there is no conflict of interests

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