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Breeding biology of the Xinjiang ground-jay *Podoces biddulphi* in the Taklimakan Desert, NW China

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ABSTRACT

The Xinjiang ground-jay (*Podoces biddulphi*), which is endemic to China, has a limited distribution and a small population in the Taklimakan Desert. In this study, we described the breeding biology and nestling growth patterns of this understudied species. Eleven nests were monitored over three consecutive breeding seasons (2017–2019). The Xinjiang ground-jay breeding season extends from March to May with a clutch size of two or three. The incubation period was 18 d, and females spent most of their time incubating their eggs (63 %), followed by collecting leaves (25 %), resting (10 %), turning the eggs (1 %), grooming (0.6 %), and being vigilant (0.4 %). Both parents fed the nestlings with similar feeding frequencies and durations. The growth curve of the nestlings was S-shaped, and the parameters related to nestling mortality, such as tarsus length, showed faster growth than others. Over the three breeding seasons, 32 eggs were laid across 11 nests. Fifteen (47 %) eggs hatched, and 12 hatchlings across six nests fledged (37.5 %). Our study provides detailed information on the breeding biology and nestling growth of the Xinjiang ground-jay. Given its low reproductive success rate, small population size, and limited distribution, this bird species, which is endemic to China, requires further research, and its conservation should be prioritized.

1. Introduction

There are four species within the genus Podoces: the Xinjiang ground-jay (*Podoces biddulphi*), Mongolian ground-jay (*P. hendersoni*), Turkestan ground-jay (*P. panderi*), and Iranian ground-jay (*P. pleskei*); however, little is known about them (Ma, 2011; Zheng, 2017).

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They tend to inhabit high-altitude deserts from Iran to Mongolia and mostly live in deserts or arid lands. The Xinjiang ground-jay is endemic to the Taklimakan Desert and the adjacent region of northwestern China (Ma, 2001). According to the Red List of Chinese Birds (Zhang et al., 2016), the Xinjiang ground-jay is a vulnerable species, and according to the IUCN Red List (BirdLife International, 2017), it is near-threatened, with a population of between 4100 and 6700 pairs (BirdLife International, 2017).

Information on the breeding biology of these four species within the genus Podoces is limited. Radnezhad et al. (2011) studied the breeding ecology of the Pleske ground-jay in Iran from 2005 to 2008. They found that Pleske's ground-jay nested at the top of the shrub and laid 5–6 eggs once a year. Only the females incubated and fed the nestlings, whereas the males watched and guarded the nest from nearby. Burnside et al. (2020) studied the breeding productivity and nest-site selection of the Turkestan ground-jay. They found that the probability of nest success from the start of incubation to fledging was only 0.186, and illegal cutting of shrubs was the main threat to this endangered species. As the only species of Podoces living in the desert, the geographical distribution, survival rates, nest-site selection, and impact of roads on the behaviour of Xinjiang ground-jay have all been examined to some extent (Ma, 1998; Ma, 2001; Ma and Kwok, 2004; Yin et al., 2005; Ma, 2011; Xu et al., 2013; Tong et al., 2018), but research on breeding remains limited. The only study related to the breeding biology of Xinjiang ground-jay reported the size of the nests, egg size, clutch size, and the main food provided to the nestlings by the parents. There have been no studies related to other aspects of reproduction, such as incubation time allocation, feeding behaviour, nestling growth patterns, and the reproductive success of Xinjiang ground-jays (Ma, 2004).

The aim of this study was to fill the knowledge gaps regarding the breeding biology of Xinjiang ground-jays. Specifically, we aimed to provide detailed information on nests, eggs, incubation time allocation, feeding behaviour, nestling growth patterns, and reproductive success. Finally, we examined how the role of each parent in rearing nestlings changed with the nestling age.

2. Methods

2.1. Study area

Our study was conducted in the southern part of the Taklimakan Desert (Xinjiang Uygur Autonomous Region, China, 37–42° N, 77–90° E) (Fig. 1) over three breeding seasons (for 3 months from March to May) between 2017 and 2019. The Taklimakan Desert is the second-largest drifting desert in the world, with more than 82 % of its area covered by drifting sand dunes. The climate is extremely arid, with an annual mean precipitation of less than 40 mm and annual evaporation exceeding 3000 mm. The annual mean temperature is 11.9 °C, with a maximum temperature of 41.9 °C in the summer and a minimum temperature of −23.9 °C in the winter (Xing et al., 2008). Sparse vegetation is typical in this area (Zhou et al., 2018).

2.2. Study species

Xinjiang ground-jays are monogamous birds, and both parents feed the young (Ma, 2011). Females perform almost all incubations (Ma, 2004). Xinjiang ground-jays exhibit male-biased sexual dimorphism, in which adult males are larger than females (Ma, 2001). Individuals can be further distinguished by the shape of the periocular black feathers around their eyes (Ma, 2004). Therefore, males and females can be distinguished by behavioural patterns and body size (Ma, 2004). Xinjiang ground-jays nest on shrubs within the oasis of the desert; their preferred primary habitat is desert with *Glycyrrhiza uralensis*, *Alhagi sparsifolia*, *Populus euphratica*, *Tamarix* spp., *Phragmites australis*, and *Lycium ruthenicum* (Fang and Hou, 2006). They prefer shrubs near available water sources and far away from oasis edges and settlements to increase food availability and reduce interference from human activities (Tong et al., 2021). The primary predators within the study area were the *Vulpes corsac*, *Buteo rufinus*, and *Athene noctua*. Xinjiang ground-jays' main food consists of insects and reptiles, such as the *Teratoscincus przewalsskii* and *Phrynocephalus axillaris* (Gao, 2005).

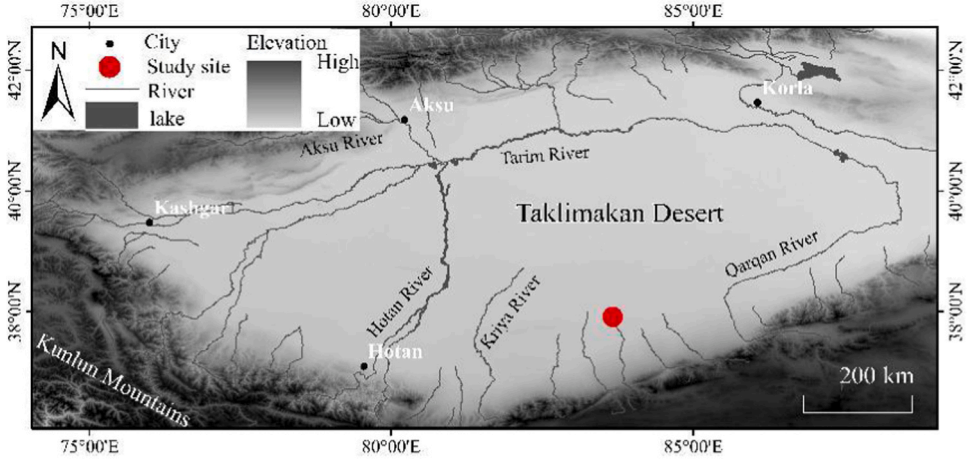

Fig. 1. Map of the Taklimakan Desert. The red point indicates the location of the study area. The background represents the elevation.

2.3. Data collection

With the help of local shepherds, we walked from 10:00–19:00 each day to visually track adult birds throughout the study area. The local shepherd lives within the 56 km^2 oasis throughout the year and knows where ground-jays can be found. When the birds were found, we stopped and marked their locations on the GPS. We then searched the entire area within a 5 km diameter around the marked location to check each shrub to find a nest. In a previous study, we found that 5 km was the average distance between two ground-jay nests; therefore, we set 5 km as the diameter of our surveyed area (Tong et al., 2018). Population density was estimated using the number of breeding pairs of Xinjiang ground-jays in the study area. The tree species, tree height, and nest height above ground, as well as nest depth, thickness, and inner and outer diameters, were recorded for each nest. We also measured the egg size and clutch size per nest. The major and minor axes of the eggs were measured using a Vernier caliper (accuracy of 0.1 mm), and egg weights were measured using an electronic balance (accuracy of 0.01 g) (Radnezhad et al., 2011).

We recorded breeding behaviours using a small (4.3 cm cubical) video camera (Yilutong M6) that was placed 0.3–0.5 m above the nest and set to record continuously. The camera was removed after the young fledged or when the nest was abandoned (Kirkham and Davis, 2013). We changed the SD cards and power source every 2 d. The video camera can connect to a mobile phone within 50 m and can then be viewed remotely. To avoid disturbances, we remotely viewed the video and approached it only when there were no adults in the nest. If an adult was present in the nest, we checked the next nest or waited until the adult left. The longest waiting time for an adult to leave the nest was approximately 1.5 h.

We divided the behaviours into two periods: incubation (before hatching) and nestling (after hatching). During the incubation period, we measured the time intervals associated with six types of behaviours in both males and females: incubation (Fig. 2b), resting, off-nest, egg-turning, vigilance, and grooming (Table 1). In addition, the duration of their absence from the nest and the number of times males fed the females were recorded. After hatching, the nestlings were checked every 2 d to observe whether there were nestling fecal sacs in the nest. This was combined with video observation to determine the feeding habits of the nestlings. We weighed all nestlings to the nearest 0.1 g on a digital balance. We measured the body, bill, wing, tail, and tarsus lengths as described by Du et al. (2015). From the video, we can easily recognize both males and females feeding the nestlings (Fig. 2c). We recorded the duration of each feeding bout and calculated male and female feeding frequencies per hour. Feeding duration was recorded when the parents started to put food into the mouth of the nestling and ended when the parent had no more food in its mouth and stopped feeding. All videos were processed by the same individual using the identified behaviours to minimize the effect of personal bias.

2.4. Data analysis

As the data were normally distributed after log transformation, we used t-tests to compare feeding behaviours between sexes using time of day, duration of feeding bouts, and number of feeding bouts. Logistic curves were used to fit the growth curves of the nestlings (Starck and Ricklefs, 1998). Data were analyzed using SPSS 21.0, and one-tailed or two-tailed tests were used depending on which was more suitable for each test; data are presented as the mean ± standard error.

3. Results

3.1. Breeding population density

In this study, we determined that the breeding density of ground-jay in the 56 km^2 study area was approximately 0.05–0.07 pairs/km^2.

3.2. Nest parameters

In the first, second, and third years, we found three, four, and four nests, respectively. None of the nests were reused during the breeding season. One nest was in the *Populus euphratica*, and ten nests were in *Tamarix spp.* Both are native trees of no economic value. Trees with nests varied in height from 249 to 564 cm, and nest heights varied from 89 to 205 cm (Table 2). We searched all shrubs in the study area for nests every year; therefore, it was certain that there were no other nests in the study area.

Fig. 2. Breeding biology of the Xinjiang ground-jay *Podoces biddulphi.* A) Nest and eggs of the Xinjiang ground-jay; b) female incubating eggs; c) female feeding the chicks (photo by Yuping Tong).

Table 1
Description of Xinjiang ground-jay behaviours.

behaviour	Description
Incubation	The female apparently settles on the eggs or provides shade for the eggs
Resting	The adult/bird/female or male is not incubating while standing on a higher branch of the bush or at the edge of the nest
Off-nest	The female/male leaves the nesting area and is out of camera range
Egg-turning	The female manipulates the eggs
Vigilance	The female or male observes the surrounding area from the edge of the nest or a nearby branch
Grooming	The female cleans the nest; the male or female grooms or smooths feathers with its beak or feet

3.3. Clutch and egg sizes

Xinjiang ground-jays laid 1–3 eggs; we found 3 eggs in ten nests and 2 eggs in one nest (32 eggs were recorded in total). The eggs were liver- or taupe-colored, with dark brown spots that were more abundant at the blunt end (Fig. 2). The average major egg axis was 3.3 ± 0.1 cm, and the average minor egg axis was 2.3 ± 0.1 cm.

3.4. Incubation time allocation

We analyzed 515 h of video from 11 nests: 355 h during daylight (6:00–21:00) and 160 h during the night (21:00–6:00). The video duration during the day varied from 2 to 15 h and at night from 3 to 9 h. The incubation period for ground-jay was 18 (16−20) d. We observed male incubation twice, each time when a female was absent from the nest for more than an hour. When the female returned, the male immediately stopped incubation. Females spent most of their time incubating eggs, whereas males spent their time guarding and occasionally feeding the females. We recorded males feeding the females 13 times during the entire 3-year study period (during which females remained incubating). Hatchling ground-jays appear to be thermoregulated when hatched. Thus, females ceased incubating and began feeding the young almost immediately after hatching, as did the males.

During the daytime, female ground-jays spent 63 ± 5 % of their time incubating, 25.1 ± 4 % off-nest, 9.9 ± 3 % resting and 1 ± 0.1 % egg-turning (Fig. 3). Grooming (0.6 ± 0.1 %) and being vigilant (0.4 ± 0.1 %) were rarely observed. Females spent significantly more time incubating in the morning (06:00–13:00, 78 ± 6 %) than in the afternoon (13:00–21:00, 47 ± 3 %) after a two-tailed test (Mann-Whitney *U test*, $Z = -10.474$, $P < 0.001$). At night, the female ground-jays slept on the nest. The female ground-jay turned eggs in the nest 3.37 times/h, preened themselves 1.1 times/h, showed signs of vigilance 4.2 times/h, and departed from the nest 1.17 times/h.

3.5. Feeding behaviour

Nestlings were fed by both parents (3.1 ± 0.3 times/h with an average feeding duration of 14.1 ± 4.1 s). Females fed nestlings 1.9 ± 0.2 times/h with a mean feeding duration of 10.9 ± 2.8 s. Males fed nestlings 1.2 ± 0.1 times/h with a mean duration of 13.6 ± 4.0 s. Feeding frequency and duration of the feeding interval were independent of sex after the two-tailed test (Mann-Whitney *U test*, feeding duration of event: $Z = -1.857$, $P = 0.063$; feeding duration per day: $Z = -0.214$, $P = 0.831$; feeding frequency per day: $Z = -1.635$, $P = 0.102$). By watching the video and analyzing the fecal sacs of nestlings not eaten by the parents, we determined that the nestling food consisted of two lizard species, *Teratoscincus* spp. (Sphaerodactylidae) and *Phrynocephalus* spp. (Agamidae), and unidentified beetles. During this study, we recorded that the parents fed the nestlings *Teratoscincus* spp. and *Phrynocephalus* spp. 12 times. Although lizards are common in the study area, they are not commonly preyed on (Gao, 2005). As most food items are small and difficult to recognize from videos, we did not have data on the proportion of food items.

3.6. Growth pattern in nestlings

The nestling period lasted 17.4 (13−21) d. At hatching, the nestlings have closed eyes, corneous beaks, and downy feathers covering most of their bodies. For the following 5–10 d, the number of downy feathers increased but did not cover the entire body. The nestlings opened their eyes at approximately 10 d of age. Their flight and tail feathers grew, and their beaks and heads darkened. The dark spots on flight feathers also increased in size after 5 d. At 10 d, contour feathers covered most of their bodies, and they could stand

Table 2
Mean ± standard deviation and range of nest parameters for 11 nests of Xinjiang ground-jays during the three breeding seasons.

Parameter of nest	Mean ± standard deviation (cm)	Range (cm)
height of a tree/shrub with a nest	370.0 ± 10.1	249.0–564.0
nest height above ground	127.0 ± 8.6	89.0–205.0
inner nest-cup depth	7.8 ± 1.2	4.2–12.3
inner diameter of nest	13.9 ± 1.4	11.1–16.3
outer diameter of nest	23.4 ± 2.6	17.8–33.6
nest edge thickness	7.0 ± 2.5	2.6–9.7

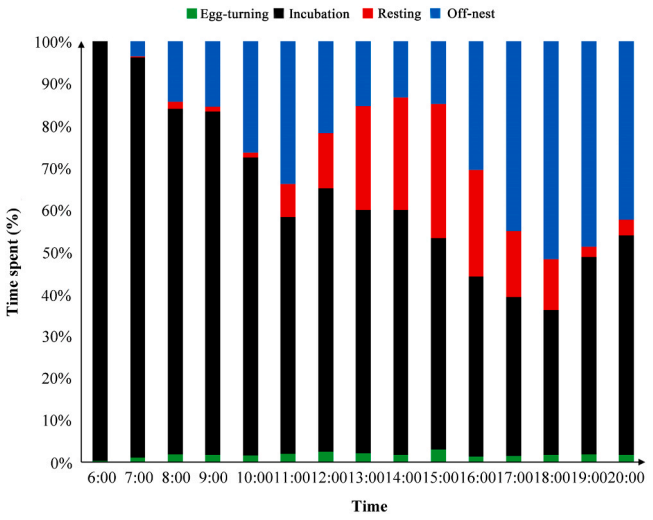

Fig. 3. Incubation behaviour time allocation during the daytime for female Xinjiang ground-jays Values are the averages over three breeding seasons for the 11 nests.

on their legs for short periods. Nestlings flapped their wings and stood on the sides of the nest. By the time the nestlings left the nest, they appeared similar to adults, although they were much smaller (Fig. 4). A logistic model was used to fit the growth curves of nestlings (Fig. 5). On d 5, the growth rates of body mass, tarsus length, and bill length were the fastest, whereas the growth rates of body, tail, and wing lengths reached a maximum on d 15.

3.7. Reproductive success

The first egg of the breeding season was laid on February 20, and fledging occurred in the nest on March 28. The last egg of the season was laid on April 22, and the fledging of the nest occurred on May 26. We recorded 11 nests with 32 eggs. Fifteen of the eggs hatched successfully, and 12 of the 15 nestlings fledged successfully (Table 3). One nest with 2 eggs and one with 3 nestlings was preyed on during the nestling period; we recorded *Buteo rufinus* preying on Xinjiang ground-jay. Three nests (each with nine eggs) were abandoned during incubation, and all three nests were abandoned the day after the sandstorm.

4. Discussion

In this study, we report detailed information about Xinjiang ground-jay's nests, eggs, incubation time allocation, feeding behaviour, nestling growth patterns, and reproductive success. This information can fill gaps in knowledge regarding the breeding biology of Xinjiang ground-jays.

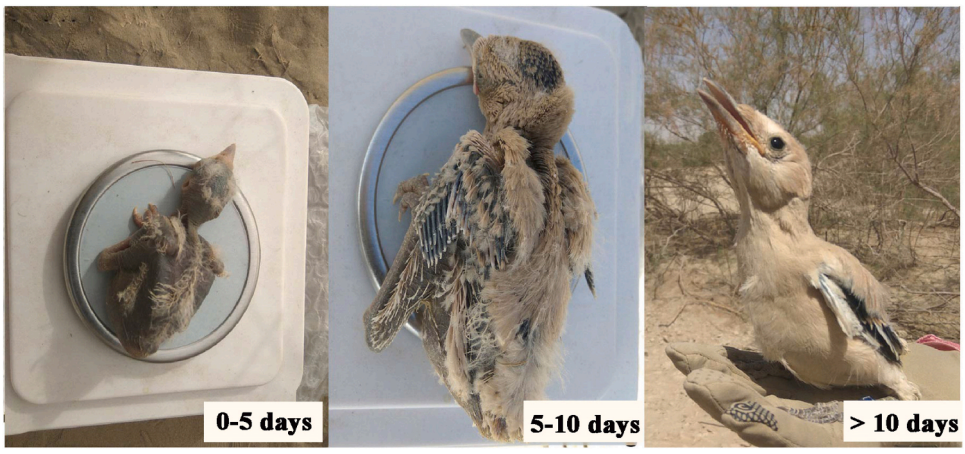

Fig. 4. Growth of Xinjiang ground-jay nestlings at 0–5 d, 5–10 d and 10 d. a) Nestling with closed eyes and corneous beak; b) Nestling with eyes open, feathers not covering the entire body; c) feathers covering the entire body and able to stand. (photo by Yuping Tong).

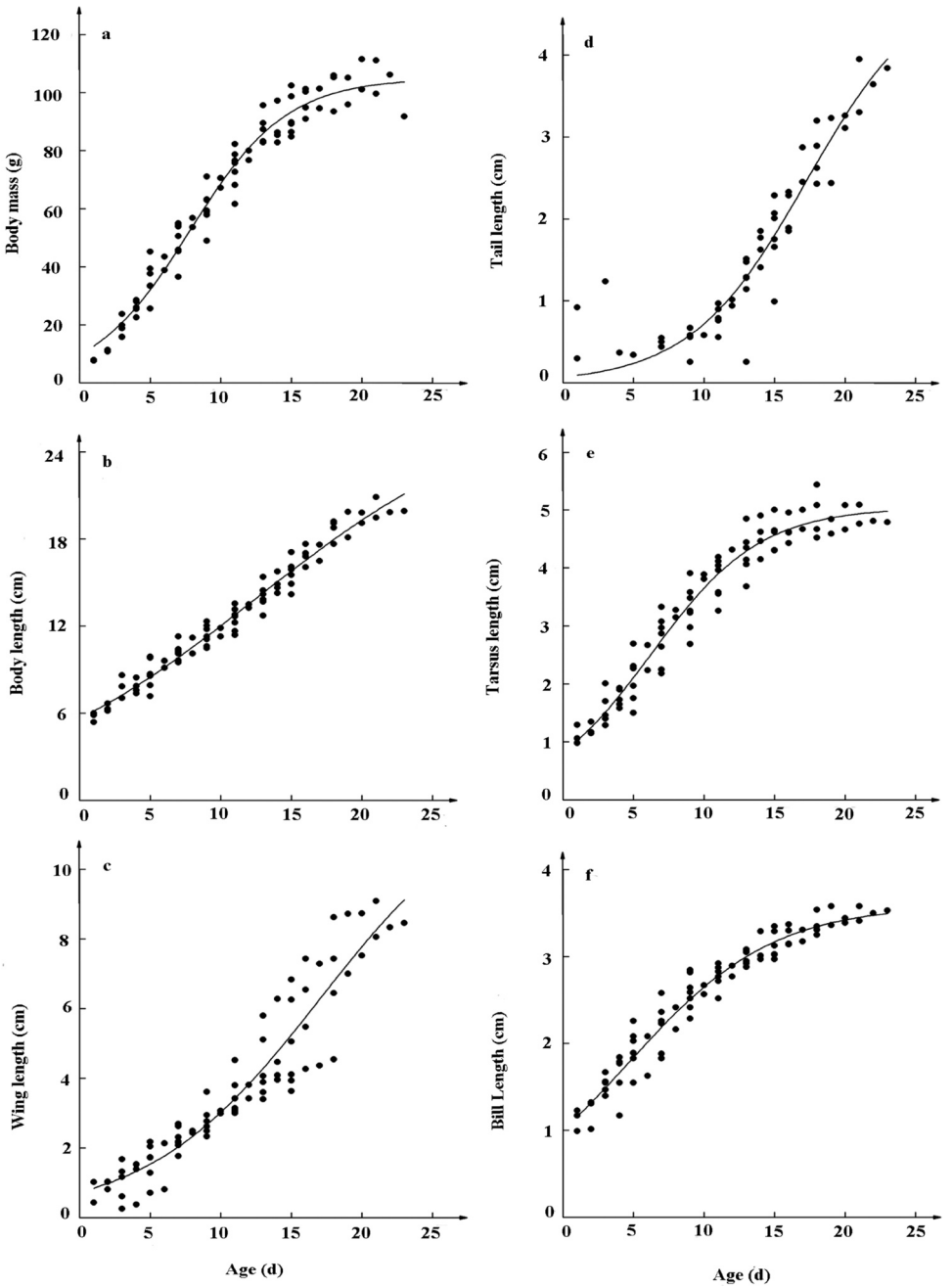

Fig. 5. Nestling growth curves for six morphological variables. a) Body mass, b) body length, c) wing length, d) tail length, e) tarsus length, and f) bill length.

Table 3
Reproductive success of Xinjiang ground-jay.

Breeding season	Number of nests	Eggs laid	Eggs hatched	Nestlings fledged
2017	3	9	2	2
2018	4	12	8	5
2019	4	11	5	5

4.1. Clutch and egg size

In the present study, we found that the clutch size of the Xinjiang ground-jay (1–3 eggs) was smaller than that of Pleske's ground-jay (4–5 eggs) (Satei et al., 2010). The reason for this difference is likely due to a disparity in the habitats of these two species. The Xinjiang ground-jay is mainly distributed in and around the harsh environment of the Taklimakan Desert, which has low precipitation, sparse vegetation, high summer temperatures, and strong winds (Zhou et al., 2018; Tong et al., 2021). In contrast, Pleske's ground-jay lives in shrubby areas with greater vegetation coverage (Satei et al., 2010). Different environments can affect reproductive output, and birds usually reduce their clutch size to increase nestling survival in harsh environments (Amundsen and Slagsvold, 1998). Compared with the study by Radnezhad et al. (2011) on the egg size of Pleske's ground-jays at three sites, the average egg size of Xinjiang ground-jays (mean ± SE; major egg axis: 3.3 ± 0.1 cm and minor egg axis: 2.3 ± 0.1 cm) were larger than the average egg size of Pleske's ground-jays (mean ± SD; major egg axis: 2.8 ± 1.5 cm, 3.0 ± 0.9 cm, 3.0 ± 1.2 cm; minor egg axis: 2.1 ± 0.6 cm, 2.2 ± 0.5 cm, 2.2 ± 0.5 cm).

4.2. Incubation behaviour time allocation

Female Xinjiang ground-jays spent most of their time incubating during the day, with longer periods in the morning than in the afternoon. This incubation strategy was similar to that of the orange-crowned warbler (*Vermivora celata*) (Conway and Martin, 2000), black-necked crane (*Grus nigricollis*) (Zhang et al., 2017), and northern bobwhite (*Colinus virginianus*). Ambient temperature is the main factor influencing the allocation of incubation time between mornings and afternoons (Conway and Martin, 2000). Constant temperatures are required for embryonic development (Kirkham and Davis, 2013; McClintock et al., 2014; Coe et al., 2015; Berntsen and Bech, 2016). Lower ambient temperatures in the morning mean that the ground-jays spend more time on the nest, keeping the eggs warm, whereas higher temperatures around noon mean that the birds have more time to break from sitting in the nest (Zhang et al., 2017). Afternoons were hot in the study area, and the female Xinjiang ground-jays modified their incubation time by reducing their time allocation around noon and into the afternoons. Female Xinjiang ground-jays also shaded the egg, which has been shown to function to cool the parent while preventing overheating of the egg in the sun (Downs and Ward, 1997).

4.3. Parental care

We found that both adult species had similar feeding frequencies and durations, demonstrating the similar effort that both males and females invested in nestling survival. In some bird species, males invest less than females because of extra-pair copulation (Gao et al., 2020). However, this was not observed in Xinjiang ground-jay. This is likely a consequence of the harsh desert environment with limited resources, such as food availability, where both parents need to contribute to the feeding and care of their nestlings. Previous studies and our own observations indicate that the Xinjiang ground-jay is strictly monogamous (Ma, 2004).

4.4. Growth pattern of nestlings

The growth pattern of the Xinjiang ground-jay nestlings followed a predictable pattern: they grew slowly immediately after hatching, then rapidly until they were close to adult body size, and then growth slowed again. This growth pattern is common in birds (Ricklefs, 1968; Zhou, 2002; Holt et al., 2016; Rodimtsev and Ermolaev, 2016; Guilherme and Souza, 2017). Among the six morphological variables, tarsus length and bill length reached their asymptotic lines faster than the others, which can be explained by predation pressure and fledgling mortality. In birds, the wings grow faster than other body parts to help avoid predators (Martin, 2015). However, in ground-dwelling birds, it is more important for nestlings to grow their tarsus faster to gain the ability to run and leave the nest quickly to escape from predators (Ma, 2004), which requires further study.

4.5. Reproductive success

In this study, we found that the reproductive success rate of Xinjiang ground-jay was relatively low. Reproductive failure can be influenced by changes in weather, nest predation, and high or low egg temperature during incubation (Ringelman and Stupaczuk, 2013; Du and Shine, 2015). From our nest-monitoring video, we found that reproductive failure was primarily caused by bad weather and nest predation. The Xinjiang ground-jay breeds in the desert area, and sandstorms follow windy days. All three times the Xinjiang ground-jay abandoned the nest happened right after the sandstorm. Therefore, we hypothesized that bad weather may be the main reason for the low reproductive success rate of Xinjiang ground-jays. Nest predation was the second main reason for the low reproductive success in this study. From the video, we recognized that the long-legged buzzard is a nest predator and one of the most common raptors in the study area (Gao, 2005). Ma et al. (2004) also reported that predators might be the main reason for nest failure and population decreases in the Xinjiang ground-jays. Therefore, it is easy to understand that it was one of the main reasons for the low reproductive success of this study.

4.6. The impact of research activities

Technological advancements have allowed for a reduction in researcher-caused disturbances but have put foreign items in close proximity to breeding activities. In this study, no nest abandonment was recorded after the initial placement of the camera in the nest.

At most, the birds stared at the camera and behaved normally. Furthermore, no behaviour change or nest abandonment was recorded after the researchers visited the nests to service the camera.

5. Conclusion

This study provides information on the breeding biology and nestling development of the Xinjiang ground-jay, a desert-dwelling species endemic to China. Xinjiang ground-jay females had smaller clutch sizes but larger egg sizes than other ground-jay species (probably due to their harsh habitat). During the incubation period, females spent more time incubating their eggs than males, and males were responsible for protecting the nest. Once hatched, males and females used similar strategies for feeding their nestlings. The growth curves of the young birds were S-shaped, conforming to the logistic curve. Morphological variables related to countering predator pressure and supporting nestling survival resulted in faster growth. The information gathered and reported in this study will help establish a deeper understanding of the Xinjiang ground-jay and assist in conservation efforts for this species.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

Acknowledgements

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Animal ethics

The animal study protocol was approved by the Animal Protection and Utilisation Committee of the Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences (license number: 20170227).

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