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# Exploring conservation strategies for oriental white stork fledglings (*Ciconia boyciana*) across the breeding wetland landscape: Hints from tracking movement patterns

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A B S T R A C T

To explore conservation strategies for endangered birds, especially for fledglings during breeding periods, the characteristics of habitat and nest site selection, daily activity pattern, and home range size must be understood. In the spring of 2016, we tracked four oriental white stork (*Ciconia boyciana*) fledglings' movement patterns in Xingkai Lake National Reserve of Heilongjiang Province in China using miniaturized multi-sensor satellite transmitters from three different artificial nests established in the same wetland fragment. Location information and hourly distance from satellite transmitters were recorded to quantify activity patterns, movement hot spots, and home range size. In this paper, we provide systematic conservation recommendations of oriental white storks with perspective on artificial nests, activity rhythms, and spatial movement patterns in the breeding landscape. Results showed that oriental white stork fledglings were more active during the daytime, significant activity peaks occurred from 03:00–05:00 A.M and from 17:00–19:00 P.M. This suggests that anthropogenic pressure should be reduced or suspended during these activity peaks and captive fledglings should feed following natural rhythms. Fledglings tended to concentrate their movement around two or three hot-spot locations with flat spaces or small ponds and their movement routes between the different hot spots presented different shapes: triangular shape, L shape, and straight line. It is necessary to create enough flat spaces or man-made ponds to support fledglings foraging. The home range area based on 100% Minimum Convex Polygons varied considerably among the four individuals, ranging from 14.79 to 39.40 km$^2$ during the tracking period. This helps determine the core protection boundary of the fledglings in the breeding habitat fragment. Establishing more artificial nests and improving nests monitoring systems are essential to ensure breeding success.



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## 1. Introduction

The oriental white stork (*Ciconia boyciana*) is a large migratory water bird that mainly breeds in Sanjiang Plain, Northeast China (BirdLife International, 2018). It was recognized as critically endangered by the International Union for Conservation (IUCN) Red List. The oriental white stork gets essential food and shelter from Sanjiang wetland patches during their breeding period, remaining there from March to September (Lu et al., 2003). However, swamp wetlands in Sanjiang Plain have been seriously degraded by human activities and climate change in the past few decades (Wang et al., 2006). Many wetlands were converted to dryland and paddy fields for food production and some were occupied by humans (Thiere et al., 2009; Wang et al., 2012). Meanwhile, natural wetland landscape fragmentation accelerated and threatened water bird habitats, especially for large birds. Furthermore, many trees used by waterbirds for nestling were destroyed (Weller, 1999). Due to these circumstances, the Chinese central government and local departments implemented several protection policies to manage wetland environments and reintroduce endangered birds, e.g. the establishment of Wetland Protection Laws (http://www.shidi.org/), the Implementation Plan for Wetland Restoration (http://www.hljdpc.gov.cn/), and Regulations on Protection of Wild Birds in Xingkai Lake National Nature Reserve (http://www.hlj.gov.cn/). Artificial nests became a vital management tool to increase the reproduction rate and population size of oriental white storks in Sanjiang Plain (Wei and Cui, 2014). The population of oriental white storks in the study area had sharply declined in the past but slightly increased under conservation strategies in recent years (Zheng et al., 2016). According to the latest statistics from China Wildlife Conservation Association (http://cwca.org.cn/), the current global population size of oriental white storks is about 9000 (https://www.sohu.com/a/432805115_620823). However, intensive monitoring of oriental white storks and conservation strategies was not adequate due to incomplete knowledge of their living conditions in artificial nests, activity patterns, and home range size, especially for fledglings. Investigating the movement patterns of fledglings from artificial nests is essential to protect fledglings and delineate strict protected areas to improve survival rate before they leave their nests. This study is critical to address systematic conservation strategies and supply information for endangered oriental white storks using artificial nests globally.

Knowledge of birds' daily activity patterns is crucial in understanding their ability to adapt to their current environment and human interference. Activity patterns and time budgets of birds are relative to their energy distribution and survival rate (Maheswaran and Rahmani, 2007). Scholars have found that activity patterns of many birds are diurnal or nocturnal (Deshler et al., 2019; Morton, 1967). However, the activity pattern of the oriental white stork has not been reported. Previous research mostly focused on instantaneous scan method and sampling using telescopes to study activity budgets and behavior of oriental white storks (Shao et al., 2015). This traditional observation method only provides behavior information over a specific location during daytime in the wild. Also, researchers usually observed captive oriental white storks in enclosures and calculated different behaviors time budget proportions including foraging, movement, resting, and breeding of selected days (Yang et al., 2013). However, previous methods cannot explore the whole days activities in the natural state. New technologies such as satellite tracking and monitoring are effective ways to assess the movement distance and activity intensity of migratory species. Currently, more and more researchers and organizations use GPS tracking to identify the migration route (Juvaste et al., 2017), habitat selection (Peng et al., 2020; Zhou et al., 2013), and suitable distribution area (Yamada et al., 2019) of adult oriental white storks. However, much less effort has been devoted to identifying movement intensity near nest sites and whether birds prefer to move during the day or night in breeding areas, especially for young fledglings. Activity pattern insights from tracking data could help clarify the movement intensity of birds to reduce human impact during peak activity. In this study, we used continuous tracking of oriental white stork fledglings in the breeding area to speculate their activity patterns and time budget before migration.

Conservation management for threatened birds relies on detailed spatial ecology information (Roth et al., 2008). Stop site selection and home range size are two crucial aspects of spatial ecology (Morganti et al., 2017; Shimazaki et al., 2004). Assessment of clumped sites of oriental white stork fledglings can be used to determine their core distribution areas (hot spots). Previous hot spot studies by ecologists focused on biodiversity hot spots on a large scale during the entire migratory period (Hu et al., 2017; Médail and Quézel, 1999). Hot spots emerged as a tool to distinguish areas of higher density used for resting or foraging. Identification of movement hot spots help to describe accurate activity areas and delineate areas requiring protection (Schools et al., 2012). Mapping hot spots can provide more valuable information for the protection of oriental white stork fledglings, as well as recommending the extent of necessary resources in those sites to maximize the conservation efficacy (Ceballos and Ehrlich, 2006). Home range is another spatial analysis which can directly reflect the wide spatial extent where birds engage in breeding, resting, foraging, and movement (Schoener, 1968). Current national reserves are not adequate for bird conservation. Home range studies could give quantitative information on the movement boundary of birds which may help estimate spatial management conservation (Veltheim et al., 2019a). Numerous home range studies focus on long-distance movement ranges of birds to determine the scope of protected areas (Jiguet and Villarubias, 2004; Williams et al., 2011). However, the movement range of fledglings is more easily threatened by breeding habitat fragmentation and human disturbance. The size of fledgling's home range near the nest can show the movement arrangement in their early life cycle. Considering the importance of oriental white stork fledglings' home range analysis, surprisingly few investigations focus on it. Xie et al. (2018) carried out a study to estimate the average home range of juvenile oriental white storks during breeding season in Honghe National Nature Reserve in Northeast China. Other studies that examined the home range size of adult white storks varied in breeding and non-breeding stages (Zurell et al., 2018). Considering that home ranges of birds are not homogeneous between individuals, strict protected areas should be proposed based on the home range of each bird in breeding habitat

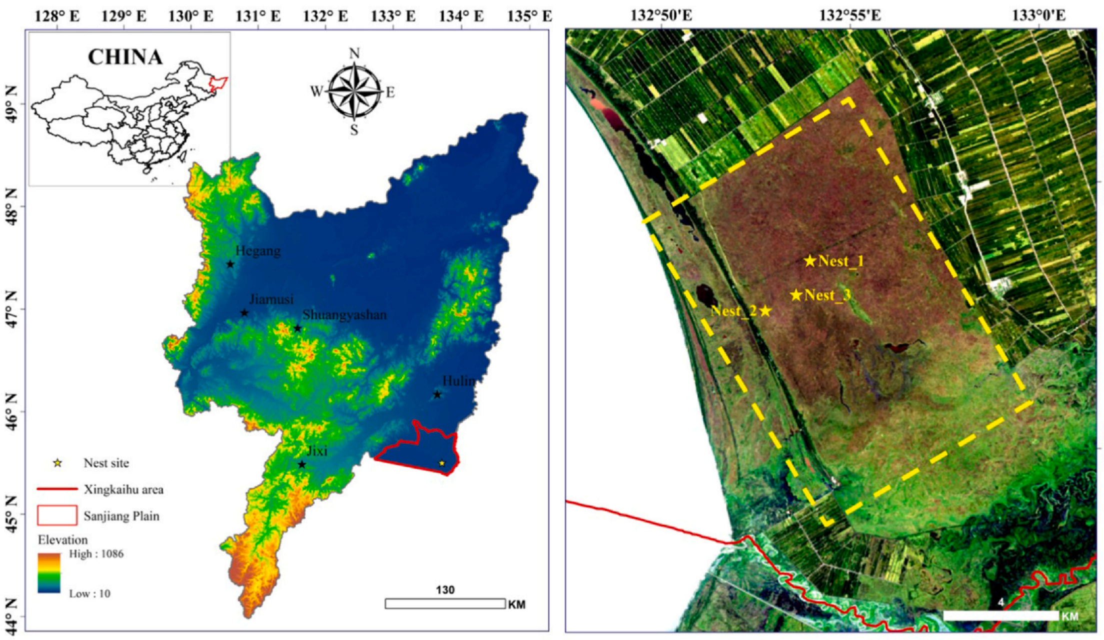


**Fig. 1.** The study region (Sanjiang Plain) for the oriental white stork in Northeast China. (Bird #1 and #2 were from Nest-1, Bird #3 was from Nest-2, Bird #4 was from Nest-3.) The image acquired by Landsat 8 with 15 m resolution was download from Geospatial Data Cloud site, computer Network Information Center, Chinese Academy of Sciences (http://www.gscloud.cn).

fragments. Our goal is to focus on the differences of hot spot sites and home range sizes of various oriental white stork fledglings before they leave the breeding area.

In this study, our objectives were to analyze fledglings' movement pattern in artificial nests including activity rhythm, hot spot area, and home range to infer conservation hints for oriental white stork fledglings in breeding habitats.

## 2. Materials and methods

### 2.1. Study area

The study area is located in Xingkai Lake National Reserve (between 45°01′N,131°58′E and 45°34′N,133°07′E), Mishan county of Heilongjiang Province, China (Fig. 1). Xingkai Lake National Reserve covers an area of 2230 km$^2$ and is the largest wetland natural reserve in northeastern china of which 300 km$^2$ is wetland. It includes DaXingkai Lake (area:1080 km$^2$) and XiaoXingkai Lake (area:170 km$^2$). This area is in the mid-temperate zone has a continental monsoon climate. The mean annual temperature ranges from 2 °C to 4 °C and the mean precipitation is about 600 mm. The unique humid climate and low slopes have formed a large area of wetlands here, providing ample habitat for endangered plant and waterbird species (Yuan et al., 2018). About 60 aquatic plant species support the growth of various herbivorous fish and amphibians, which in turn provide abundant food for wetland birds (Xun et al., 2009). It has been estimated that about 210 bird species inhabit Xingkai Lake and many first level protected birds remain there for breeding (Liu and Wang, 2016).

The observed oriental white stork fledglings' nests are in a large wetland patch (Fig. 1). This wetland is the core marsh area near the Long Wang Miao building (45°04′05″N,132°52′44″E). The fledglings remained here for about 1 month before summer migration. The area of this wetland fragment is about 106.89 km$^2$. There is a one-way road (average 8 m width) inside the wetland, but it is rarely used by humans. During the breeding period, the fledglings can fly across the road to forage. This area is a flat plain with a mean elevation of 68 m. The main soil type is hydromorphic soil (marsh meadow soil). The dominant plant species in the observed area include *Glyceria spiculosa, Phragmites communis*, and *Deyeuxia angustifolia* (Song et al., 2011). Since the reintroduction of oriental white storks to Xingkai Lake National Reserve in 1990, this wetland has become one of their major breeding areas.

### 2.2. Tracking data

We attached miniaturized multi-sensor satellite transmitters to the four oriental white stork fledglings from three nests (Bird #1 and #2 were from Nest-1, Bird #3 was from Nest-2, Bird #4 was from Nest-3) in Xingkai Lake National Reserve on July 6th,2016. The miniaturized multi-sensor satellite transmitters model was HQBG3621S produced by HQXS company (HuanQiuXinShi) in Hunan province, measuring 55(L) × 26(W) × 36(H) mm and weighing 24 g. The transmitters were set onto

**Table 1**
Summary of satellite tracking data for the 4 oriental white stork fledglings from Xingkai Lake National Reserve.

| Nest ID | Bird ID | No.of location points | Tracking days | Tracking period (MM/DD/YY in GMT) | Nest departure date (YY/MM/DD CLOCK in GMT) | Early chick-rearing period | Late chick-rearing period |
|---|---|---|---|---|---|---|---|
| Nest1 | #1 | 730 | 31 | 7/6–8/5/2016 | 8/1/2016 9 am | 7/6–8/1/2016 | 8/1–8/5/2016 |
| Nest1 | #2 | 1044 | 44 | 7/6–8/18/2016 | 8/2/2016 4 am | 7/6–8/5/2016 | 8/5–8/18/2016 |
| Nest2 | #3 | 719 | 31 | 7/6–8/5/2016 | 7/15/2016 11 am | 7/6–7/15/2016 | 7/15–8/5/2016 |
| Nest3 | #4 | 760 | 31 | 7/6–8/5/2016 | 7/19/2016 13 pm | 7/6–7/19/2016 | 7/19–8/5/2016 |

to the backs of the oriental white stork fledglings. The geographical location of the transmitters was determined by Argos and information including latitude and longitude pairs, flight altitude, and movement speed per time unit was recorded based on the geodetic datum WGS84. All recorded locations were transmitted to users by Global System for Mobile Communication (GSM). The equipment accuracy was 5 m and the position data accuracy index (Location Class, LC) was categorized into five class (LC A, B, C, D, and null). The level of position accuracy for each LC was defined according to the standard deviation of location error (< 5 m for LC A; between 5 and 10 m for LC B; between 10 and 20 m for LC C; between 20 and 1000 m for LC D; and > 1000 m for LC null). In this paper, we select LC A, B, and C as effective locations.

The oriental white stork fledglings were tracked from July to August in 2016, a total of 3253 effective locations of the four birds were recorded (Table 1). According to the movement ability and movement range, we divide the record period into two stages: Early chick-rearing period and Late chick-rearing period. In the early chick-rearing period, the fledglings had weak movement ability, only moved near the nest, and returned to the nest every day. In the late chick-rearing period, the birds had the ability to fly or move far from the nest and did not return to the nest every day.

### 2.3. Calculation of travel distance

The geodesic distance based on UTM (Universal Transverse Mercator) projection was used to calculate the move distance from one point to another. Transmitters recorded one point every hour.

To measure bird movement ability, average distance per hour was selected to quantify the basic characteristics of these fledglings.

(1) Average hourly distance ($\bar{S}$)

The movement distance per hour was defined as the distance between the two consecutive records at a 1-h interval:

$$\bar{S} = \sum_{i=1}^{n} \sqrt{(x_{i+1} - x_i)^2 - (y_{i+1} - y_i)^2} / n \tag{1}$$

Where n is the number of times recorded in 1 h, x and y represent the longitude and latitude based on the UTM (Universal Transverse Mercator) projection, respectively

(2) Maximum hourly distance ($S_{max}$)

Represents the largest value of the distance within every hour:

$$Smax = Max \sum_{i=1}^{n} \sqrt{(x_{i+1} - x_i)^2 - (y_{i+1} - y_i)^2} / n \tag{2}$$

Where n is the number of times recorded in 1 h, x and y represent the longitude and latitude based on the UTM (Universal Transverse Mercator) projection, respectively.

### 2.4. Assessing the activity pattern

To assess whether the activity pattern of oriental white storks was diurnal or nocturnal, we first define the diurnal period and nocturnal period. Diurnal and nocturnal periods were defined based on the times of sunrise and sunset derived from the websites https://www.timeanddate.com/sun. The diurnal period (the period of daylight) is the time from sunrise to sunset. The nocturnal period (the period of darkness) is the time from sunset to sunrise the following day (Fraser et al., 2019). During the tracking period, the median sunrise time was 03:48 (ranging from 03:35–04:01), and the median sunset time was 18:55 (ranging from 19:06–18:44). Movement between the diurnal period and the nocturnal period was compared. Independent T-test was used to test if there were differences between diurnal activity and nocturnal activity. Statistic tests were performed with the software IBM SPSS 23.0 (SPSS Inc. Chicago, IL, USA), the test significance was $P = 0.05$.

### 2.5. Hot spot estimation

To understand utilization intensity of different places in the breeding area, we used ArcGIS 10.3.1 (ESRI, Redlands, CA, USA) and location data to estimate the location density. Kernel density analysis allows patterns of locations to be transformed into a matrix of utilization distribution, the two-dimensional probability distribution of estimated location is based on utilization distribution (Bontadina and Naef-Daenzer, 1996). The estimate is based on an algorithm (the kernel function) that defines which sites are included and the weight of these locations. According to the satellite location, nonparametric estimation of spatial distribution was used to predict the probability of species appearing in a region using the equation:

$$\mathrm{f(x)} = \frac{1}{nh^2}\sum_{i=1}^{n} K\left[\frac{x - X_i}{h}\right] \tag{3}$$

where f(x) is the probability distribution function, $n$ represent sample size, the kernel K is a unimodal symmetrical bivariate probability density function, and $h$ is the smoothing parameter that can be selected by the user (Silverman, 1986, 2018).

The most common technique of kernel estimation is the bivariate normal kernel, which weights locations according to bivariate Gaussian distribution and has its maximum at the grid point being processed. The grid size was based on kernel density estimations and the resulting matrix of density can be described by contour plots, the core area and the range of movement hotspots will be identified for further analysis (Wood et al., 2000).

### 2.6. Home range analysis

Home range is defined as the area traversed by an animal in its normal activities including feeding, sheltering, and nesting (Burt, 1943). Much information for threatened species such as space-use range and behavioral responses can be revealed by home range estimations (Silva et al., 2018). In order to better understand the oriental white stork fledglings' spatial movement range, we charted the movement range areas of the oriental white stork fledglings using 100%, 95% and 50% minimum convex polygon (MCP) with Home Range Extension Software (Rodgers, 2007; Rodgers et al., 2007a, 2007b). MCP is one of the most extensive methods to estimate movement range area in water bird studies (Anders et al., 1998; Buenestado et al., 2008). MCP is more straightforward than other methods as it is not affected by grid cell size or location density (Harris et al., 1990). Minimum convex polygon (MCP) is calculated by the equation:

$$A = \frac{x_1(y_n - y_2)\sum_{i=2}^{n-1} x_i(y_{i-1} - y_{i+1}) + x_n(y_{n-1} - y_1)}{2} \tag{4}$$

Where A is the home range area, $x_i$ and $y_i$ represent the latitude and longitude of the oriental white stork location, and n is the sample size. In this study we use 100%, 95% and 50% MCP to measure the home range of the oriental white stork fledglings in the research period (Moss et al., 2014; O'Donnell, 2001). The 100% MCP denotes the boundary of the home range including all location points, but the result of 100% MCP is likely influenced by occasional excursions from the center of activity. The 95% MCP excludes 5% of the observations most peripheral to harmonic mean (Russo et al., 1997) and shows the area normally used by animals (Mysterud, 1999). The result of 50% MCP reflects 50% of the locations of oriental white stork fledglings which can represent the core area of home range (Etter et al., 2002). The results of 100% MCP, 95% MCP, and 50% MCP were computed onto layers and exported as maps by ArcGIS to show the movement range size of each oriental white stork.

## 3. Results

### 3.1. Basic movement characteristics of the oriental white stork fledglings

Bird #1, #3, and #4 stayed in the breeding habitat for 31 days and Bird#2 stayed for 44 days before starting long distance migration. The mean distance per hour of the tracking period ranged from 0.10 to 0.26 km. The hourly movement distance during late chick-rearing period was about 5–8 times larger than that in early chick-rearing period, maximum distance during late chick-rearing period was about 4–13 times larger than that in early chick-rearing period (Table 2). The differences between diurnal and nocturnal movement in each period were significant ($P < 0.05$) for the four fledglings (Table 2). The movement

**Table 2**
The results for basic movement characteristics and movement patterns of the oriental white stork fledglings in total period, early chick-rearing period (EP) and late chick-rearing period (LP). Comparisons were made for separate individuals between EP and LP.

| Bird ID | Basic movement characteristics | | | | Different between diurnal and nocturnal movement | | |
|---|---|---|---|---|---|---|---|
| | Average hourly distance (km) | Period | Average hourly distance (km) | Maximum hourly distance (km) | Average diurnal movement (m) | Average nocturnal movement (m) | *P* value |
| #1 | 0.10 | EP | 0.05 | 1.40 | 63.17 | 41.37 | $P < 0.05$ |
| | | LP | 0.41 | 6.06 | 562.91 | 150.96 | $P < 0.05$ |
| #2 | 0.17 | EP | 0.06 | 1.19 | 68.11 | 34.68 | $P < 0.05$ |
| | | LP | 0.36 | 7.13 | 512.36 | 109.56 | $P < 0.05$ |
| #3 | 0.26 | EP | 0.05 | 0.47 | 53.83 | 33.28 | $P < 0.05$ |
| | | LP | 0.35 | 6.53 | 463.59 | 184.88 | $P < 0.05$ |
| #4 | 0.16 | EP | 0.05 | 0.54 | 61.35 | 30.55 | $P < 0.05$ |
| | | LP | 0.25 | 4.09 | 341.82 | 112.16 | $P < 0.05$ |

distance per hour in the daytime was significantly longer than at night for all four fledglings in early chick-rearing period and late chick-rearing period. The mean diurnal movement was 61.35–68.11 m in early chick-rearing period and 341.82–562.91 m in late chick-rearing period. The mean nocturnal movement distance was 30.55–41.37 m in early chick-rearing period and 109.56–184.88 m in late chick-rearing period.

### 3.2. Daily activity rhythm

The activity rhythm during the tracking period revealed a movement pattern with multiple peaks of activity (Fig. 2). The four fledglings showed similar activity patterns during early chick-rearing period, late chick-rearing period, and for the whole period. The activity of fledglings showed sharp peaks at specific times: near sunrise, midday, and sunset. All fledglings had the first activity peak in the early morning from 3:00–6:00, decreasing rapidly before 8:00 a.m. There were multiple peaks during daytime, the last peak occurred from 17:00–19:00 p.m. prior to sunset. The peak hour near midday was more obvious in late chick-rearing period than early chick-rearing period and the activity pattern in the whole period was similar to late chick-rearing period. Activity decreased sharply during the evening, remaining low before twilight.

### 3.3. Movement hot spots

The four oriental white storks' movement in the breeding area displayed different patterns varying by period (Fig. 3). Bird #1 and bird #2 in early chick-rearing period concentrated their movement at three specific hotspots around the nest site but showed dispersive distribution during late chick-rearing period. In the early chick-rearing period, they traveled between three hot spots and the route between the hotspots showed a "Triangular path" their movement trajectory had a high repetition rate up to 89.26%. The location of bird #3 and #4 displayed cluster distribution both in early chick-rearing period and late chick-rearing period. Bird #3 concentrated its activity in three hot spots and the routes showed an "L-shape". Bird#4 traveled in a straight route between two hot spots. The distance individuals traveled between hotspots varied. Bird #1 and bird #2 had a shorter distance between hotspots on average (0.3 km) in contrast to bird#3 (3.12 km) and bird#4 (3.26 km).

### 3.4. Home range analysis

The home range sizes of the four oriental white stork fledglings in the breeding area ranged from 0.003 to 39.4 km$^2$ depending on the individual, movement period, and the utilization distribution of MCP estimates (Fig. 4). The 100% MCP included all of the bird's locations and produced larger estimates from 14.79 to 39.40 km$^2$ during the breeding period (Table 3). The 95% MCP included the main activity areas of fledglings ranging from 6.10 to 14.24 km$^2$. The 50% MCP represented the core home range of fledglings ranging from 0.08 to 6.15 km$^2$. There was considerable variation in home range of fledglings between early chick-rearing period and late chick-rearing period. Home range sizes in late chick-rearing period were much larger than early chick-rearing period. The home range size using 100% MCP varied from 0.13 to 1.16 km$^2$ in early chick-rearing period and from 14.53 to 39.40 in late chick-rearing period. The 95% MCP produced smaller estimates from 0.07 to 0.08 km$^2$ in early chick-rearing period and 6.42–8.10 km$^2$ in late chick-rearing period. The home range size estimated by 50% MCP varied between 0.003 and 0.02 km$^2$ in early chick-rearing period and 0.29–6.73 km$^2$ in late chick-rearing period.

## 4. Discussion

### 4.1. Conservation management implications inferred from artificial nest sites

Installing artificial nests had a noticeably positive effect for protection of large birds with no nesting trees (Bakka et al., 2020). This is because providing suitable artificial nests can increase nest site availability and population number of vulnerable birds (Libois et al., 2012). Hence, artificial nests have become a popular management tool globally for monitoring and protecting endangered bird species, including seabirds (Bolton et al., 2004; Priddel and Carlile, 1995), Psittacidae (Olah et al., 2014), raptors (Sonerud, 1985), and waterbirds (Savard and Robert, 2007). In the oriental white stork breeding area of Northeast China, artificial nests are the most common conservation approach to introduce and recover population size. Since the reintroduction of oriental white storks in 1990, more than 200 nests have been built in Sanjiang Plain. Current artificial nests in the study area for oriental white storks mainly consist of 3 types (Fig. 5). All fledglings from our research are from wooden structure artificial nests. Although artificial nests successfully enhance the recovery of the oriental white stork population, the cost and structure of nests still needs improvement. We suggest popularizing wooden artificial nests because the materials are lighter, inexpensive, locally available, and are more easily built than iron structures. Regular inspection and maintenance of artificial nests needs to be a concern of managers to increase their durability and ensure the return of birds in the following breeding year. Additionally, miniature remote cameras should be installed inside artificial nests to better monitor nestling success rate and behavioral ecology of oriental white storks (Dixon et al., 2009). By using remote cameras, managers can reduce the frequency of nest maintenance as well as reducing the stress to birds caused by scientific observers (Proudfoot, 1996).

Since artificial nests have proven to be one of the best ways to reintroduce oriental white storks and enhance population recovery (Zhang et al., 2000), it is important to increase the number of artificial nests in national reserve areas for oriental white stork breeding. The efficiency of artificial nest sites is affected by human interference, food limitation, predator attraction, and

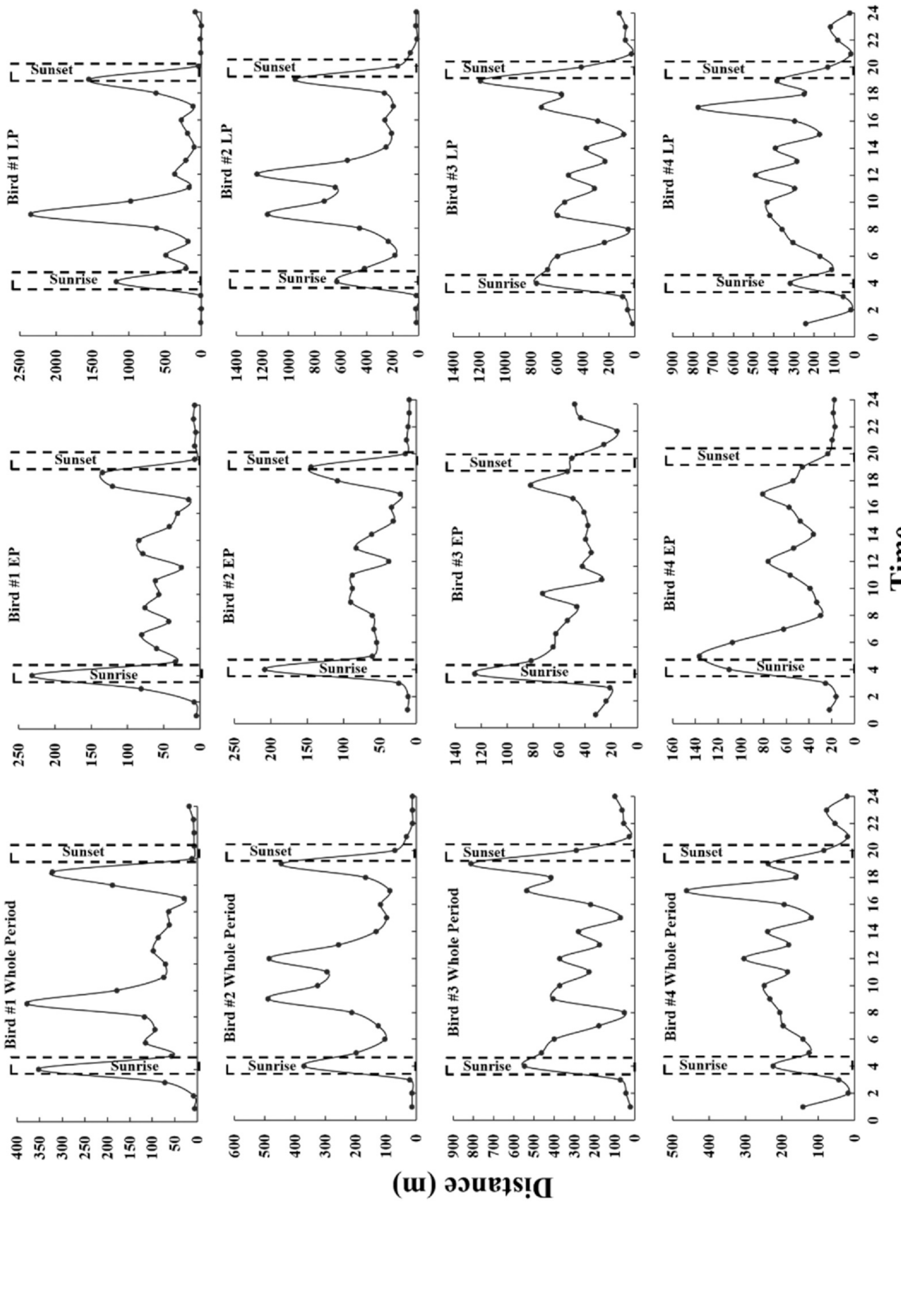


**Fig. 2.** Daily rhythm of activity of the oriental white stork fledglings. EP means early chick-rearing period. LP means late chick-rearing period.

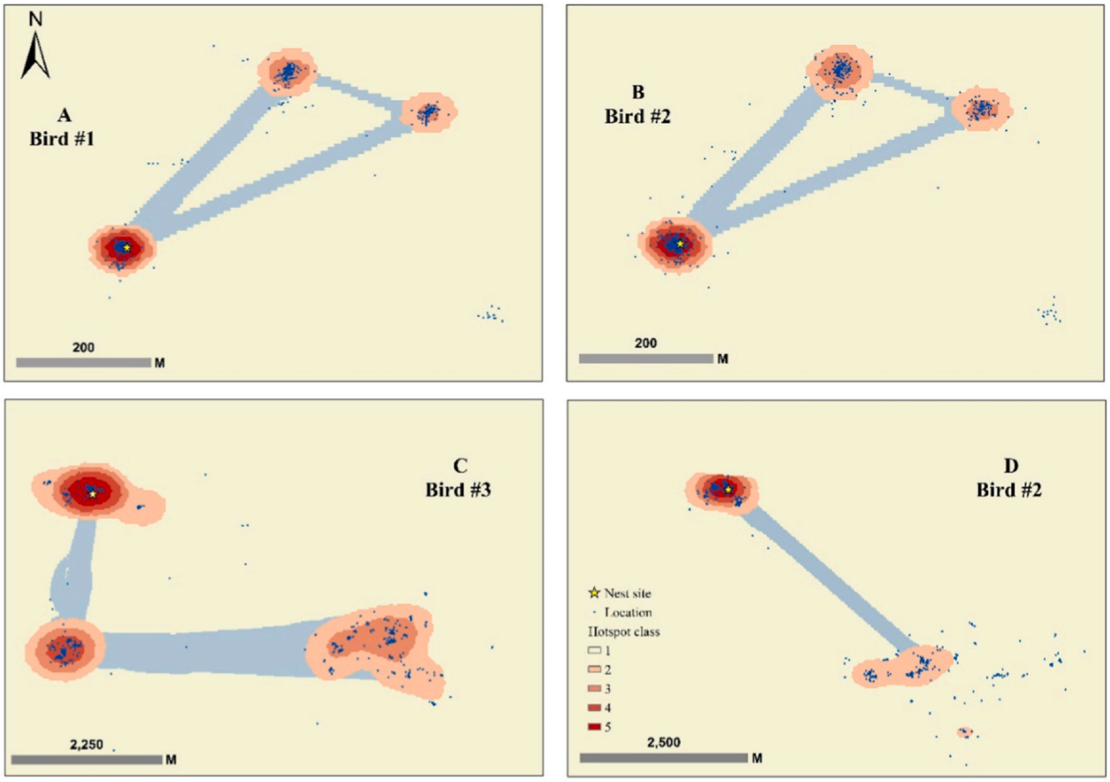


**Fig. 3.** Kernel density analysis to estimate the hot spots of oriental white storks.

nest interval (Lewis et al., 2009). Some studies reported that the minimum distance from the oriental white stork nest to an area of human interference (residence or road) was about 1.10 km (Duan et al., 2011; Zhu et al., 2008). In the present study, we note that the distance from nest #2 (Bird #3) to the road is only 0.62 km which is smaller than the threshold value of 1.1 km, indicating that this bird could easily be affected by human activity or cars (Table 4). Evidence shows that human activities may cause stress in waterbirds, with harmful consequences on nest occupancy (Tavares et al., 2015). As a result, bird #3 was more alert than the other birds and switched between more stop sites. The distance between Nest #1 and Nest #2 is about 2.3 km, Nest #1 and Nest #3 is about 1.3 km, and Nest #2 and Nest #3 is about 1.2 km. Previous studies showed that due to intra-specific competition, oriental white stork would not occupy artificial nests which were near other nests (Wang and Li, 2006). The distance between artificial nests should be more than 1 km to make sure there is enough territory for oriental white stork to move and forage (Li 1995). Our study suggests that oriental white storks can occupy artificial nests with an interval of 1.2 km. The distance of 1.2 km between one nest and another does not affect the growth and activity of oriental white stork fledglings. Also, arranging nests in a safe place with sufficient food can improve nest conservation efficiency (Newton, 1998). Our study demonstrates that fledglings concentrated all their activities around the artificial nest in the early chick-rearing period, therefore putting artificial nests near ponds or food rich areas will reduce their movement distance to forage and reduce predation risk. Building artificial nests in the core area of the swamp far away from roads and farmlands is beneficial to increase nest occupation rate and protect oriental white storks from human interference on a long-term scale.

### *4.2. Conservation management implications inferred from movement ability and activity rhythm*

According to previous studies, oriental white stork fledglings grow quickly, they can stand up at nearly 40 days and their movement ability increases rapidly 50 days after they are born (Luan, 1997). In the early chick-rearing period, fledglings only moved a short distance around the nest and returned to their nests every day. In the late chick-rearing period, fledglings moved or flew farther away from the nests. The hourly movement distance and maximum distance in late chick-rearing period are much larger than those in early chick-rearing period. Another study reported that the active distance of oriental white stork fledglings in the breeding area was from 0.41 km to 7.71 km per day, varying with different periods. This result is similar to our study (Xie et al., 2018). Fledglings (Bird #1 and #2) from the same nest had similar average hourly distance and maximum hourly distance in early chick-rearing period. The movement route of bird #1 and #2 also overlapped with each other during early chick-rearing period (Fig. 2). This situation is likely attributed to the movement routine following their parents (Jiao, 2014). In the late chick-rearing period, fledglings from the same nest had different movement routes, indicating they could leave their

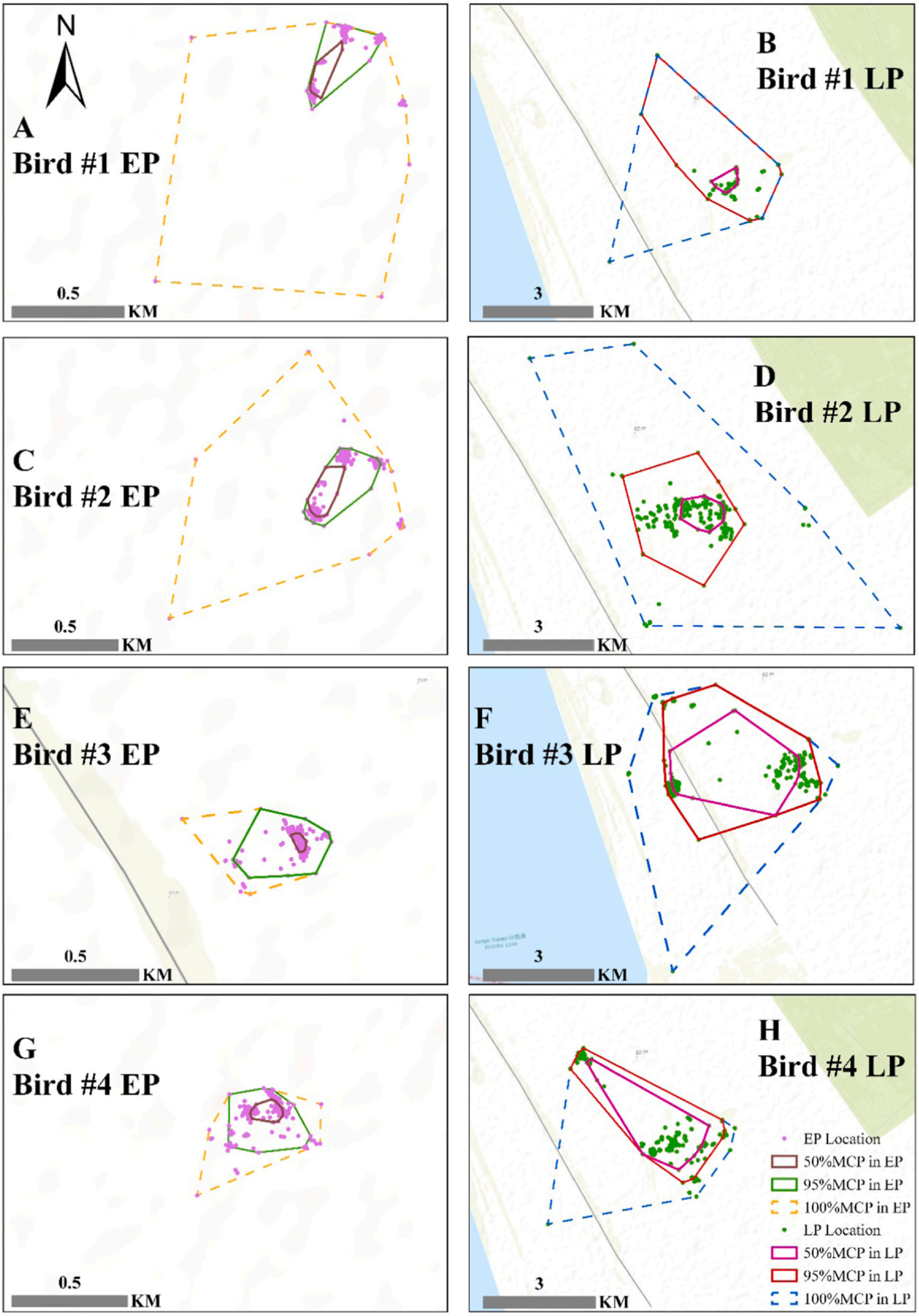


**Fig. 4.** Individual home ranges (MCP, at 100% and 95% contours) of the oriental white stork fledglings in early chick-rearing period (EP) and late chick-rearing period (LP).

**Table 3**
Home range estimates of oriental white stork fledglings (n = 4) in their breeding areas in Xingkai Lake Natural Reserve, analyzed by Minimum Convex Polygon ( MCP ) . EP represent early chick-rearing period. LP represent late chick-rearing period.

| Bird ID | 100% MCP ($km^2$) whole period | 95% MCP ($km^2$) whole period | 50% MCP ($km^2$) whole period | 100% MCP ($km^2$) EP | 100% MCP ($km^2$) LP | 95% MCP ($km^2$) EP | 95% MCP ($km^2$) LP | 50%MCP ($km^2$) EP | 50%MCP ( $km^2$ ) LP |
|---|---|---|---|---|---|---|---|---|---|
| #1 | 17.08 | 6.10 | 0.08 | 1.16 | 14.53 | 0.07 | 8.10 | 0.02 | 0.29 |
| #2 | 39.40 | 13.53 | 4.43 | 0.80 | 39.40 | 0.07 | 7.46 | 0.02 | 0.87 |
| #3 | 24.95 | 14.24 | 6.15 | 0.13 | 24.95 | 0.08 | 12.66 | 0.003 | 6.73 |
| #4 | 14.79 | 6.40 | 0.27 | 0.15 | 14.77 | 0.07 | 6.42 | 0.01 | 3.90 |

parents and forage by themselves. The hourly movement distance of adult oriental white storks can reach 14 km, much larger than fledglings (Peng, 2020). Current studies on observation of wild animal activity are limited to daylight, therefore activity data of oriental white storks is only diurnal (Shao et al., 2015). Our study found that oriental white stork fledglings are more active during daytime. Although movement intensity and distance are significantly lower during the night, oriental white stork fledglings were not completely inactive at night. Another study showed that the oriental white stork fledglings spend more time resting at during night, but they still have other behaviors or movements such as preening, walking, or maintaining vigilance (Xing et al., 2020). European white storks are more active during the daytime but may begin foraging trip during the night (Johst et al., 2001).

Investigating temporal activity patterns can reveal ecological behavior of birds and provide essential insights into how birds cope with human interference during their daily activities. Our results showed that oriental white storks activity has multiple activity peaks. Many large birds, such as the Northern Goshawk *Accipiter gentilis* (Christian, 2006) and Mexican Spotted Owl *Strix occidentalis lucida* (Delaney et al., 1999), also showed similar activity rhythms, even reaching activity peaks around dawn and dusk (Aschoff, 1966). This daily biologic rhythm shown by many birds and mammals is due to physiological reasons and environmental factors (Aschoff, 1966; Helm and Visser, 2010). Birds always catch most of their daily food in the morning before sunset (Rijnsdorp et al., 1981). Activity peaks around sunrise and sunset paralleled their primary prey: *Oplicephalus orgus*, *Perccottus glenii,* loaches (Biswas and Ramteke, 2008), and small amphibians and reptiles (Oishi et al., 2004). In addition, birds' activity rhythm is also driven by temperature and light (Ruchi and Malik, 2015). In high-temperature environments, birds reduced activity at midday to decrease metabolism expenditure on (McNamara et al., 1994). However, some birds intensively foraged during a peak time at midday in suitable temperatures to balance predation and starvation (McNamara et al., 1994). Oriental white stork fledglings' significant multiple activity peaks around sunrise or sunset and during the day maximized prey and minimized starvation.

Time budgets of captive oriental white storks showed that feeding, resting, and walking has two peaks in a day (Liu, 2001; Tian, 2005). Resting time usually occurred from 9:00–10:00 and 12:00–13:00, feeding was 11:00–12:00 and 15:00–16:00, walking mainly occurred from 11:00–12:00 and 14:00–15:00 (Liu, 2001). In another study, captive oriental white storks rested during midday and late afternoon and walked from 8:00–9:00 and 16:00–18:00. Their feeding behavior is mainly concentrated at 7:00, 11:00, and 17:00–18:00. The movement peak was later than the resting peak (Tian, 2005). However, captive oriental white storks showed less foraging time and more resting time due to human feeding. Wild birds spend more time moving and

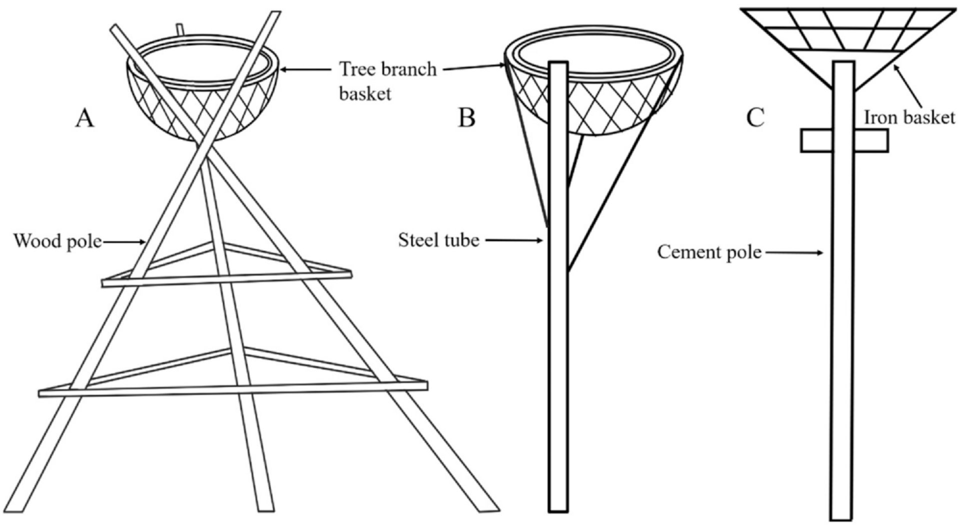


**Fig. 5.** Major types of artificial nest structure for oriental white storks (A: wooden tripod structure, B: steel tube structure, C: cement pole structure). The height of the nest is from 3 to 17 m, the inner diameter of the nest baskets is about 50 ~ 70 cm.

**Table 4**
The distance from each artificial nest to roads, farmlands, and buildings.

| Nest ID | Distance from road (km) | Distance from farmland (km) | Distance from building (km) |
|---|---|---|---|
| Nest #1 | 2.80 | 4.13 | 7.76 |
| Nest #2 | 0.62 | 4.65 | 6.73 |
| Nest #3 | 1.85 | 4.83 | 6.49 |

foraging searching for adequate food (Shao et al., 2015). Wild oriental white storks tend to forage from 4:00–10:00 and 16:00–18:00 and rest from 22:00–4:00 (Xing et al., 2020). In our study, fledglings were more active during daytime because there is high water transparency at that time, thus prey are more easily captured from the water surface (Zhou et al., 2013). Motion decreased after activity peaks and continued at a low level for a long period from 13:00–16:00 when the fledgling likely rested. Activity rhythm was different between captive oriental white storks and wild ones. Minimizing human proximity to oriental white storks is important for conservation and the distance needs to be greater according to activity rhythms of wild birds.

### *4.3. Conservation management implications inferred from spatial movement patterns*

Hot spots are important protected areas which are more likely and frequently to be used by birds. In this study, we only explored the hot spots of oriental white stork fledglings within their breeding landscape. The presence points of bird #1 and #2 showed clumped distribution in early chick-rearing period and dispersed distribution in late chick-rearing period. Bird #3 and #4 showed clumped in both periods. The route between different hot spots reflected the optimal movement strategy of oriental white stork fledglings. Birds tend to minimize energy cost and predation risk during migration to improve foraging efficiency (Alerstam, 2011). The greatest concentration of repeated routes of oriental white stork fledglings occurred between hot spot areas which indicated fledglings may minimize time and energy use in this way. Keeping connectivity between hot spots from being influenced by human activity is conducive to oriental white stork fledgling protection. According to Google Earth images (Fig. 6), hot spots were concentrated on three kinds of areas: near nest, around flat places in swamp areas, and areas along small ponds. The largest concentrated area of fledglings is near small water surface areas (Fig. 6). This is because waterbirds prefer to

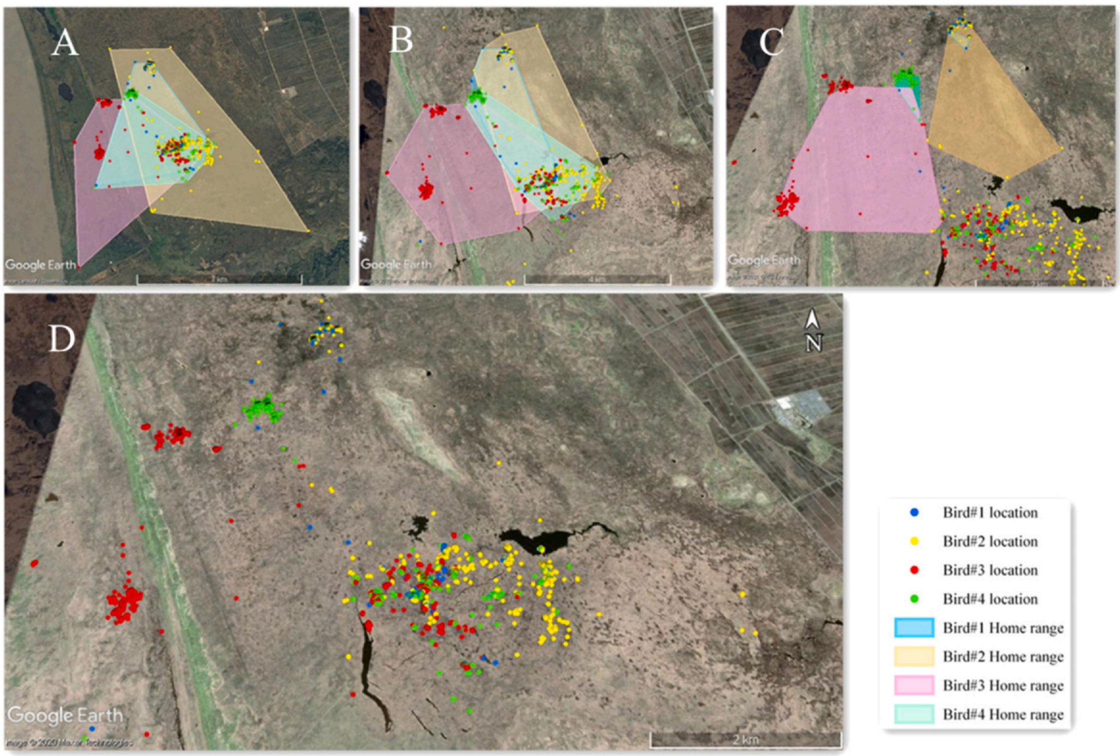


**Fig. 6.** The concentration areas and home range of four fledglings. All locations of four fledglings was mapped at D. The 100% MCP home range of all locations was mapped at A, 95% MCP home range was mapped at B, and 50% MCP home range was mapped at C. The background image was downloaded from Google Earth (http://earth.google.com).

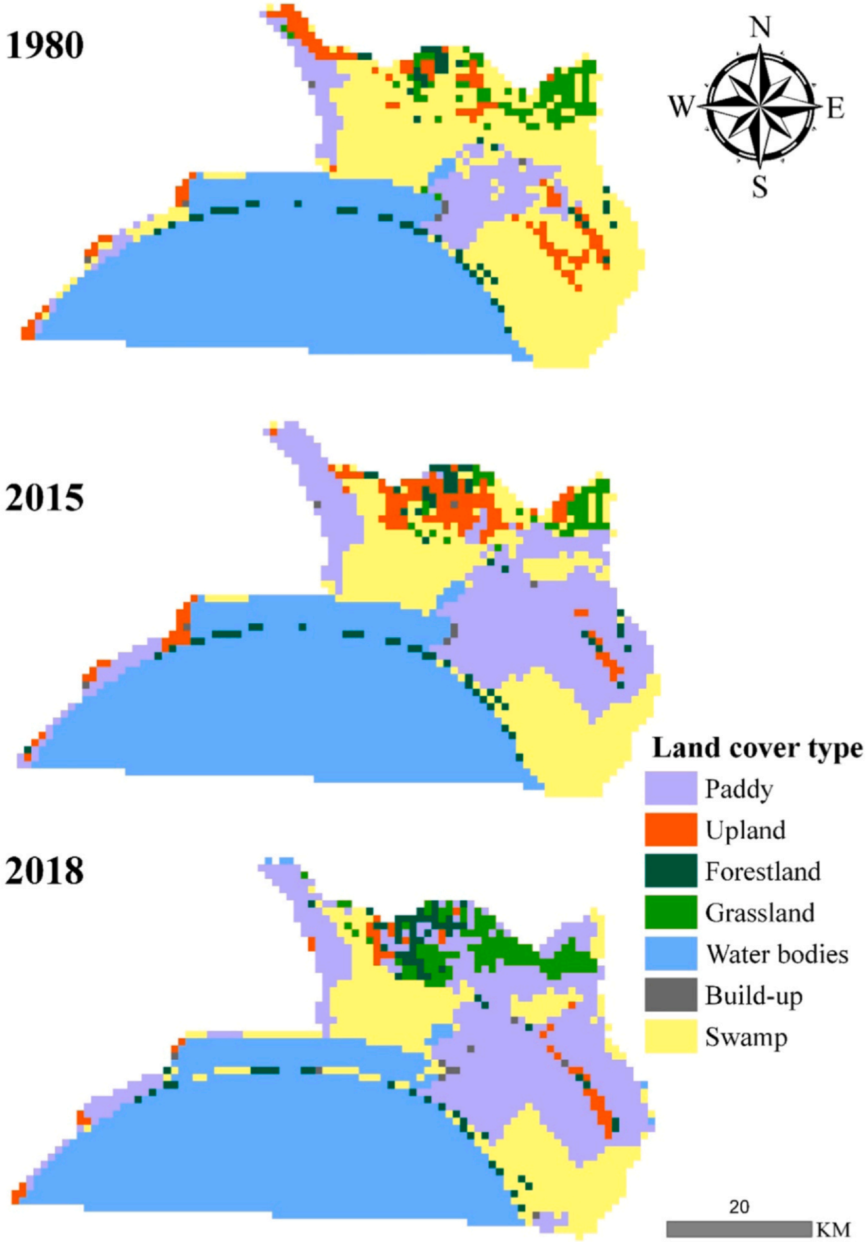


**Fig. 7.** The land use type in Xingkai Lake National Reserve in 1980, 2015, and 2018.

stay near shallow water where they can acquire abundant food (Naito et al., 2014). Food availability in water bodies determines bird distribution (Amat et al., 2005). In years of extreme drought, the water level of ponds or shallow waters becomes low or even dries up, resulting in shortage of prey. Under these conditions, oriental white stork fledglings lose suitable foraging sites and spend more time seeking food. So, management should focus on maintaining the water level of small ponds or supplying artificial water ponds near nests. Man-made ponds should not be too concentrated, otherwise, the water birds won't be dispersed (Ma et al., 2010).

Our study provides a reliable conservation management system that establishes the core protection area of oriental white storks and emphasizes the integrity of the movement area in the breeding habitat patch. We estimated home range areas for the 100%, 95%, and 50% contours MCP to explore the spatial demands of oriental white stork fledglings. Although the 100% MCP is sensitive to outliers, it can include all movements of oriental white storks which is essential for protection area design. We found that home ranges of the oriental white stork fledglings were concentrated in intact swamps and did not spread to farmland or water bodies, also these fledglings home ranges extensively overlap with each other. The study of lower fragmented swamps suggested that populations had higher foraging success rate and less interference there. Home range of oriental white storks vary between stage during the whole summer migration (Xie et al., 2018). Population density, food distribution and habitat quality can affect home range size (McNab, 1963; Schoener, 1968). The result of previous home range studies of same species in Honghe National Nature Reserve, Heilongjiang Province is two times larger than our study, indicating that the breeding habitat wetland may contain adequate resources required by fledglings (Xie et al., 2018). It is common to find differences in home range size across numerous bird individuals (Veltheim et al., 2019b). Wetland integrity and proportion of suitable habitat area directly influence the activity range of oriental white stork fledglings. However, extensive agricultural activities and climate warming cause deterioration of swamps in our study area (Zhou et al., 2009). As for land-use type in Xingkai lake area, swamps constituted 34% of the area in 1980 decreasing to 21% in 2015, and only remained 18% in 2018 (Fig. 7). Many swamp areas were converted to paddy fields due to agriculture expansion since 1980, affecting waterbird habitats. The loss and fragmentation of habitat may increase bird movement costs and reduce home ranges (Hinam and Clair, 2008). Our study greatly contributes to the view on home range requirements of oriental white storks at breeding habitat landscapes, suggesting important conservation strategies for them. Protection areas should envelope the largest home range required by oriental white stork fledglings. In an attempt to avoid or reduce the impact of habitat loss, conservation strategies are setting a buffer around each home range as a minimum protection area. Effective long-term conservation strategies should not only protect wetland areas around nests that oriental white storks currently need, but also need to predict future habitats needs to develop a broader conservation range. The current management of protecting waterbird habitats mainly focuses on established national reserves and reclaiming cropland back to wetland (Chen et al., 2020). Nevertheless, regulations and policies seem to be insufficient. Local people in Xingkai lake area can enter the national reserve freely, affecting the activity of oriental white storks. Also, the public expanded the agricultural area for economic reasons alone without considering ecological conservation. Hence, it is necessary to increase the public's awareness of the rules to protect water birds and reduce human activity in the core breeding habitat of oriental white storks. Blocking roads near the breeding habitat during breeding season will also reduce impact on oriental white storks. Further studies must be carried out to monitor oriental white storks in artificial nests to implement effective conservation systems.

## 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.

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