Movement and home range of cinereous vulture *Aegypius monachus* during the wintering and summering periods in East Asia

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**Abstract:** The present study was conducted to elucidate the movement and home range of 7 subadult cinereous vultures *Aegypius monachus* during the wintering and summering periods using a telemetry system from January 2015 to March 2017 in East Asia. In total, 7053 locations (180–1607 points per bird) were used to analyze the home range size and movement distance of the birds during the wintering, migration, and summering periods. The tracked birds overwintered in South Korea. They migrated between South Korea and Mongolia during spring and autumn, respectively. Their movement and home range size varied considerably throughout the annual cycle between the wintering and summering grounds. The migration route and home range exhibited considerable overlap among the vultures tracked. Further studies on breeding ecology and habitat use pattern are necessary for the conservation of cinereous vultures and their habitats in the wintering and summering grounds.

**Key words:** Conservation, migration, Mongolia, South Korea, telemetry system

Vultures offer invaluable ecosystem services such as reduction of infectious disease transmission via removal of carrion within food webs (Ogada et al., 2012b; Benbow et al., 2015). With their soaring flight, vultures can move between widely separated foraging locations. Further, migration, wintering, summering, and breeding influence the spatial ecology of vultures. They fly over huge areas with overlapping home ranges throughout their annual cycle (Rivers et al., 2014). However, during the last few decades, the population of vultures has been declining significantly on a global scale. Today, most vultures are considered threatened (Ogada et al., 2012a; Cortés-Avizanda et al., 2016; IUCN, 2017).

The range of cinereous vulture *Aegypius monachus* extends from South Europe to East Asia. In the Old World, this species is known as the largest bird of prey (Clark, 1999; Batbayar et al., 2008). The species has been listed as Near Threatened in the Red List of Threatened Species by the International Union for Conservation of Nature (IUCN) (Cultural Heritage Administration, 2016). The population of cinereous vultures has declined significantly in Asia and Europe (Yamaç and Bilgin, 2012). The major threats are associated with anthropogenic activities leading to poisoning and lack of food resources for these birds (Gavashelishvili et al., 2012).

In Europe, the vulture population is well monitored (IUCN, 2017). However, data on migration, movement, and home range of vultures in East Asia are scarce. Only a few studies have been conducted on the distribution and migration of cinereous vultures in East Asia (Cultural Heritage Administration, 2016). Sufficient data on the habitat use pattern of the species are necessary for their conservation. It is also important to understand their movement and home range in the wintering and summing grounds (Martin et al., 2007).

Knowledge on the movement and home range of vultures is relatively limited. Furthermore, vultures exhibit immense behavioral plasticity in their habitats (Holland et al., 2017). A global positioning system (GPS)-wideband code division multiple access (WCDMA)-based telemetry system enables recording the complete journey of the vultures. The present study evaluated repeated journey records of cinereous vultures, broad-front migrants, obtained using the GPS-WCDMA-based telemetry system.

The tracked birds migrated between their wintering site in South Korea and summering site in Mongolia.

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The objective of the present study was to understand the habitat use pattern of the cinereous vulture based on the movement and home range during the wintering and summering periods in East Asia.

On 18 January 2015, seven subadult cinereous vultures (four males and three females) were captured using cannon nets in their wintering ground and fitted with GPS-WCDMA-based transmitters (Model WT-200) in Kiweol (34°59′9.9″N, 128°19′16.7″E), Goseong County, Gyeongsangnam Province, South Korea (Table 1). The transmitter was attached to the back of each bird using a Teflon ribbon harness (Ueta et al., 2000; Kenward, 2001). The size of the GPS-WCDMA-based transmitter (KoEco Inc.) was 80 mm (L) × 45 mm (W) × 40 mm (H). It weighed 180 g, which was less than 3% of the body mass of the bird. The tracking period was from 18 January 2015 to 15 March 2017.

Location data of the birds were acquired using the GPS and transmitted via a public mobile phone system network. If the birds were out of the coverage area of the public mobile phone network, the location data were saved in their respective transmitters. The saved data were transmitted when the birds returned to the coverage area. The transmitters recorded locations at 0100 and 1300 hours of every day (2 locations per day) based on battery life. The location error was less than 50 m. The battery life of the transmitter used in the present study was more than 2 years.

In total, 7053 GPS positions (180–1607 points per bird) were used to analyze the home range size and movement distance of the birds during the wintering (late October to late April), migration (spring migration: late March to middle May, autumn migration: early October to middle December), and summering (early April to middle November) periods. The proportion of successful location (obtained locations/scheduled locations) was 97%. The home range of each vulture was estimated using the dynamic Brownian bridge movement model (dBBMM) with the move package in the R program (Kranstauber et al., 2012; Holland et al., 2017).

A 95% home range was defined as the general individual home range and 50% home range was defined as the core area. The outlying 5% of fixes during the estimation of the 95% home range was excluded. The home range sizes of cinereous vulture between the wintering and summering periods were compared by Mann–Whitney U test. Daily movement distance was calculated by cumulative straight-line distances between an original point and daily range centers. The daily movement distance among the wintering, migration, and summering periods was compared by the Kruskal–Wallis test.

In the present study, seven subadult cinereous vultures were captured and fitted with transmitters on 18 January 2015. The mean overwintered days of the tracked birds was 129 days in South Korea. Moreover, the mean period of spring and autumn migrations was 18 days. The vultures started their spring migration to Mongolia on 23 March. Furthermore, autumn migration started on 9 October. The duration of stopover was different for each tracked bird. Some birds performed movement each day without any staying during migration. Other birds did stopovers for more than one night at certain places for resting and feeding. The mean summering period of vultures was 191 days in Mongolia.

Three tracked birds (VK 1501, VK 1502, and VK 1503) migrated between South Korea and Mongolia for over 2 years. Birds VK 1504 and VK 1505 overwintered in South Korea. However, the signals from their respective transmitter were lost after the first wintering period. The signals from VK 1506 and VK 1507 were received for 15 months. They migrated between South Korea and Mongolia during spring and autumn, respectively (Figures 1a–1h). The largest distance a bird traveled was 347 km during spring migration and 435 km during autumn migration.

The daily movement of the tracked birds ranged between 12 and 25 km/day during the wintering period in South Korea. However, their daily movement increased to 96–178 km/day during the migration period. Furthermore, the daily movement distance ranged between 35 and

<table>
<thead>
<tr>
<th>Individual</th>
<th>Sex</th>
<th>Age</th>
<th>Tracking period</th>
<th>No. of tracked days</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK 1501</td>
<td>Male</td>
<td>Subadult</td>
<td>18 Jan 2015 to 14 Mar 2017</td>
<td>787</td>
</tr>
<tr>
<td>VK 1502</td>
<td>Male</td>
<td>Subadult</td>
<td>18 Jan 2015 to 14 Mar 2017</td>
<td>787</td>
</tr>
<tr>
<td>VK 1503</td>
<td>Female</td>
<td>Subadult</td>
<td>18 Jan 2015 to 15 Mar 2017</td>
<td>788</td>
</tr>
<tr>
<td>VK 1504</td>
<td>Male</td>
<td>Subadult</td>
<td>18 Jan 2015 to 16 Apr 2015</td>
<td>89</td>
</tr>
<tr>
<td>VK 1505</td>
<td>Female</td>
<td>Subadult</td>
<td>18 Jan 2015 to 9 Apr 2015</td>
<td>82</td>
</tr>
<tr>
<td>VK 1506</td>
<td>Male</td>
<td>Subadult</td>
<td>18 Jan 2015 to 12 Apr 2016</td>
<td>451</td>
</tr>
<tr>
<td>VK 1507</td>
<td>Female</td>
<td>Subadult</td>
<td>18 Jan 2015 to 17 Apr 2016</td>
<td>456</td>
</tr>
</tbody>
</table>
Figure 1. Migration route of cinereous vultures (a) VK 1501, (b) VK 1502, (c) VK 1503, (d) VK 1504, (e) VK 1505, (f) VK 1506, (g) VK 1507, and (h) total birds tracked using the GPS-WCDMA-based transmitter in East Asia from January 2015 to March 2017.
Figure 1. (Continued).
Figure 1. (Continued).
Figure 1. (Continued).
57 km/day during the summering period in Mongolia. The daily movement distance was significantly different between the wintering, migration, and summering periods (Kruskal–Wallis test, $\chi^2 = 936.947, P < 0.001$) (Table 2).

During the wintering season, the home range size of cinereous vultures was 1752 km$^2$ (95% HR - home range) and 185 km$^2$ (50% HR). During the summering period, the home range size increased significantly to 23170 km$^2$ (95% HR) and 2885 km$^2$ (50% HR). The home range size of the tracked vultures was significantly larger during the summering period than during the wintering period for 95% HR ($Z = –7.246, P < 0.001$) and 50% HR ($Z = –7.361, P < 0.001$) (Table 3).

Understanding the migration and habitat use patterns of endangered species is essential for their conservation and management (Lee et al., 2017). Migratory birds have different summering and wintering sites (Vasilakis et al., 2008; Kang et al., 2017). In the present study, the movement and home ranges of 7 subadult cinereous vultures in East Asia were determined. However, comparison of movement and home range between sexes was difficult due to the low number of vultures tracked. The mean traveled distances of tracked birds were 18 and 48 km/day during the wintering and summering periods, respectively. However, the birds traveled significantly longer distances during migration. The mean distance traveled was over 110 km/day during migration.

Most of the radio-tracked cinereous vultures migrated from South Korea to Mongolia in the spring. Furthermore, in the autumn, they migrated from their summering ground to South Korea. This suggests that the species regularly migrate between South Korea and Mongolia (Batbayar et al., 2008). The migratory route of the tracked birds varied between individuals. The birds migrated to Mongolia via North Korea and China (Figures 1a–1h).

The home range of the species is determined by the availability of resources throughout the year. It is also influenced by the distribution of critical resources (Margalida et al., 2011; Rivers et al., 2014). In the present study, the home ranges of the individuals varied significantly within and between seasons. The home range size during the summering period in Mongolia was significantly larger than that during the wintering period in South Korea. The core area of the vultures was small during the wintering period before increasing in size during the summer through the breeding season.

### Table 2. Difference in the daily movement (km/day, mean ± SE) of cinereous vultures tracked in East Asia from January 2015 to March 2017 analyzed by Kruskal–Wallis test.

<table>
<thead>
<tr>
<th>Individual</th>
<th>Period</th>
<th>Mean ± SE</th>
<th>$\chi^2$</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wintering</td>
<td>Migration</td>
<td>Summering</td>
<td></td>
</tr>
<tr>
<td>VK 1501</td>
<td>25.66 ± 1.27</td>
<td>178.59 ± 14.01</td>
<td>52.55 ± 2.38</td>
<td>195.138</td>
</tr>
<tr>
<td>VK 1502</td>
<td>21.64 ± 1.17</td>
<td>103.23 ± 9.67</td>
<td>47.83 ± 2.17</td>
<td>130.577</td>
</tr>
<tr>
<td>VK 1503</td>
<td>16.39 ± 1.30</td>
<td>102.94 ± 9.55</td>
<td>49.10 ± 2.14</td>
<td>242.991</td>
</tr>
<tr>
<td>VK 1504</td>
<td>12.24 ± 1.77</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>VK 1505</td>
<td>15.60 ± 1.47</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>VK 1506</td>
<td>13.06 ± 0.75</td>
<td>96.54 ± 12.11</td>
<td>35.35 ± 2.21</td>
<td>117.017</td>
</tr>
<tr>
<td>VK 1507</td>
<td>13.61 ± 0.90</td>
<td>120.84 ± 11.34</td>
<td>57.37 ± 33.36</td>
<td>211.813</td>
</tr>
<tr>
<td>Total</td>
<td>18.26 ± 0.50</td>
<td>117.61 ± 5.24</td>
<td>48.89 ± 1.10</td>
<td>936.947</td>
</tr>
</tbody>
</table>

### Table 3. Difference in the size of home ranges (km$^2$, mean ± SE) between the wintering and summering periods of cinereous vultures tracked in East Asia from January 2015 to March 2017 analyzed by Mann–Whitney U test.

<table>
<thead>
<tr>
<th>Home range</th>
<th>Period</th>
<th>Mean ± SE</th>
<th>Z</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wintering</td>
<td>Summering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>95% HR</td>
<td>1752.91 ± 244.55</td>
<td>23170.51 ± 2987.58</td>
<td>−7.246</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>50% HR</td>
<td>185.12 ± 30.34</td>
<td>2885.42 ± 473.38</td>
<td>−7.361</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
Scavenger species have adapted to unpredictability with respect to food resources. Furthermore, predictability and availability of food resources can be modified by anthropogenic activities (Wilson and Wolkovich, 2011; López-López et al., 2013). In the present study, it was observed that in South Korea, the habitat use pattern was intensive and the food resources were relatively more abundant for the species during the wintering period. However, the home ranges of the cinereous vultures were located in pasturelands during the summering period. The birds traveled over huge expanses in search of carrion in Mongolia (Cultural Heritage Administration, 2016). They are known to depend on livestock of nomadic pastoralists in their summering grounds. The cinereous vultures depend on the pastureland and stock animals for their primary food resources (Bedunah et al., 2006; Batbayar et al., 2008). Furthermore, they preferred the pastureland owing to better soaring conditions and easier detection of food (Vasilakis et al., 2008; Gavashelishvili et al., 2012).

The present study provided basic information on the movement and home range of the cinereous vulture in East Asia. The movement and home range size of the tracked vultures varied considerably throughout the annual cycle between the wintering and summering grounds. The migration routes and home ranges of the birds showed a considerable overlap. A relatively high activity pattern during the summering period might be attributed to the habitat conditions of the pasturelands. In the future, breeding ecology and habitat use patterns of the cinereous vultures should be studied in relation to the food resources and human land use in the wintering and summering grounds of the bird.

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