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Original Article

Migration of Grey Heron from the Peter the Great Bay and the potential transmission routes of avian influenza

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ABSTRACT

Eight nestlings of Grey Heron were captured in the Peter the Great Bay, Primorskii Territory, Russia and were deployed with trackers supporting GPS and Mobile Phone in May 2017. In total, 35,166 records on the locations of the birds were obtained over the study period until November 18, 2019. The tracking data were available for seven birds in autumn 2017, three birds from spring to autumn 2018, two birds in spring 2019, and only a single bird in autumn 2019. We could trace the migration routes accurately and locate the places for feeding and resting of the Grey Heron during the post-nesting period and seasonal migrations. The direction of the migration of the Grey Herons in autumn was southwest, and it was northeast in spring without exception. With tracking data, we found that there were two main patterns of migration of the Grey Heron: fast and delayed migration. The Grey Heron has been frequently reported to be affected by highly pathogenic avian influenza, and thus, a possibility that infected Grey Heron delivers avian influenza virus in East Asia had been discussed.

Introduction

The Grey Heron (*Ardea cinerea*) is a typical migrant and a locally nesting species in Primorskii Territory (Russian Federation). It has rarely been registered during the winter season in that region. Most of the nesting colonies of the Grey Heron are found from reed beds and flooded willows in Prikhankaiskii lowland. They are also found from the Ussuri river valley and its tributary (Bikin river, Bolshaya Ussurka River, etc.) and along the basins of some rivers where the precipitation is collected and drains off into the East Sea (Elsukov 1999; Labzyuk 1990; Shibnev 1975; Spangenberg 1940; Vorobiev 1954). In addition, the colonies of Grey Heron are found from islands of the Peter the Great Bay; the biggest colonies are located in Furugelma and Russkii Islands. It has been reported that the total number of birds nesting in the Primorskii Territory is about 2200 pairs (Gluschenko et al. 2016; Tiunov and Katin 2020).

To investigate the migration of the Grey Heron at the Far Eastern Russia, banding of nestlings of the Grey Heron had been done for the colonies of the Khanka Lake from 1960 to 1973. A total of 3520 Grey Herons had been banded, and among them, the return of 89 were registered and 15 were found dead or killed in wintering grounds in Thailand, Vietnam, Southern China and Yangtze River basin, southern Japan, or Korean Peninsula (Ilyichev 1978; Polivanov and Polivanova 1971). However, there is very limited information on the routes of the seasonal migration of the Grey Heron in East Asia. In the last decade, the studies on the migration of birds have progressed greatly with location tracking devices using Global Positioning System (GPS) with Mobile Phone Communication technologies. This equipment is deployed to the birds, determining the location of the birds periodically and sending those data to the user. For an ecological study, a GPS-Mobile Phone tracker was attached to one adult Grey Heron, which wintered at the Dongting Lake of the Yangtze River basin in 2014, and the seasonal migration of this bird was recorded between

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the breeding area in the Jewish Autonomous region, Russia and its wintering site in China for 2 years (Ye et al. 2018). In the same way, in South Korea in 2014, the post-breeding dispersion and migration of a young Grey Heron were studied using a Platform Transmitter Terminal (PTT) equipped with a GPS (Kim et al. 2015). In this study, we also used GPS-Mobile Phone trackers to trace the migration of the juvenile Grey Herons that nest in colonies in the Peter the Great Bay in the Russian Far East, and we collected and analyzed the geographical and temporal data of their migration.

As millions of birds of different species migrate in their own global flyways that are interconnected to each other and some of them gather in their common breeding sites, the chances of virus infection, circulation, and evolution increase during their co-mingling. Particularly, all the countries sharing the East Asian-Australasian flyway like South Korea, Russia, China, Japan, and Southeast Asian countries are likely to be influenced from those birds sharing that flyway. Because the Anseriformes (ducks, geese, and swans) and Charadriiformes (gulls, terns, and waders) are the major natural reservoir of avian influenza virus and there is convincing evidence that migratory birds can play a crucial role in the generation and interregional dissemination of highly pathogenic avian influenza (HPAI) virus, relevant knowledge of the bird migration becomes more necessary to assess the influence of their migration on the occurrences of that disease. Especially, for the last two decades, the viral strain of the H5 subtype of avian influenza, emerged from Guangdong China in 1996, has evolved and expanded with great genetic diversity, and the viruses have spread in many countries in Asia, Europe, and America, causing great economic losses in poultry (Lee et al. 2015). During the course of the outbreaks of HPAI in poultry in those countries, many species of wild bird were also affected with the same viruses, and it was shown that their infections are correlated in temporal and spatial aspects (Poen et al. 2019). In January 2017, a novel HPAI virus of a subtype H5N8 clade 2.3.4.4 was identified from a dead Grey Heron in South Korea (Woo et al. 2017). From the phylogenetic analysis, it was proposed that the virus might be a descendant of the viruses that had circulated in waterfowl in Siberia and underwent recombination with some low pathogenic avian influenza viruses of Eurasian lineage before its introduction into the Korean peninsula (Woo et al. 2017). Similarly, the isolation of an HPAI virus of a subtype H5N6 from the dead heron had been reported in Guangzhou, Guangdong province, Southern China in October 2013 and this strain was very closely related to the viruses isolated in poultry in that region in 2013 (Luo et al. 2018). In March 2019, an HPAI virus of a serotype H5N2 of an Asian lineage was detected in a dead Grey Heron in Guandu Park in Taipei, Taiwan, and it is not clear where it had been infected with that virus (OIE; World Organization for Animal Health).

Material and methods

On May 28–29, 2017, eight Grey Heron nestlings were taken from the nests, and GPS-Mobile Phone trackers, WT-300 made by KoEco Inc., were attached to them on their back and fastened to the wing. This device collects the latitude and longitude coordinates using GPS and transmits the data every 2 h using a mobile phone network. The tracker is 38 × 66 × 19 mm in size, and it weighs 42 g. The Grey Herons were from the colonies located in two different islands of the Marine Reserve of the Peter the Great Bay: the one is in the Furugelma island (42.28 N, 130.55 E) and the other is in the Kamni Butakova island (42.27 N, 130.48 E), separated from each other by 7.5 km in distance. From each colony, four nestlings of Grey Heron were chosen; their identification number were fg1701, fg1702, fg1705, and fg1706 for the birds of Furugelma Island and kb1703, kb1713, kb1715, and kb1719

Table 1. Tracking information for the seasonal migrations of the Grey Herons captured in the Marine Reserve of the Peter the Great Bay from 2017 to 2019.

ID	Leaving date from the breeding colony in 2017	Autumn 2017			Spring 2018		Autumn 2018			Spring 2019		Autumn 2019		
		Duration of southbound migration	Flight distance during the migration (migration pattern)	Wintering location during 2017–18	Duration of northbound migration	Flight distance during the migration (migration pattern)	Duration of southbound migration	Flight distance during the migration (migration p attern)	Wintering location during 2018–19	Duration of northbound migration	Flight distance during the migration (migration pattern)	Duration of southbound migration)	Flight distance during the migration (migration pattern)	Wintering location during 2019–20
fg1701	Jun 27	Oct 16–Nov 12 (27 days)	4250 km (delayed)	Thailand	May 14–Jun 5 (22 days)	4097 km (delayed)	Oct 2–Oct 3 (1 Day)	710 km (fast)	South Korea	–	–	–	–	–
fg1702	Jun 26	Sep 29–Oct 7 (11 days)	4759 km (fast)	Thailand	May 10–Jun 22 (43 days)	4456 km (delayed)	Data missing	–	Thailand	Apr 10–Apr 23 (13 days)	4271 km (fast)	–	–	–
fg1705	Jul 2	Oct 14–Oct 20 (6 days)	3735 km (fast)	China	–	–	–	–	–	–	–	–	–	–
fg1706	Jul 1	Oct 3–Oct 5 (2 days)	1705 km (fast)	China	–	–	–	–	–	–	–	–	–	–
kb1703	Jun 28	Oct 20–Oct 31 (11 days)	4830 km (delayed)	Thailand	–	–	–	–	–	–	–	–	–	–
kb1713	Jun 27	Oct 1–Nov 3 (33 days)	4919 km (delayed)	Thailand	–	–	–	–	–	–	–	–	–	–
kb1719	Jun 23	Oct 29–Oct 31 (2 days)	1583 km (fast)	China	Mar 31–Apr 17 (17 days)	1694 km (wandering)	Oct 24–Oct 30 (6 days)	1538 km (fast)	China	Mar 16–Mar 18 (2 days)	1417 km (fast)	Oct 11–Oct 13 (2 days)	1490 km (fast)	China

for Kamni Butakova Island. The fg1701 and fg1705 are from the same nest, and so are fg1702 and fg1706, and kb1703 and kb1715 are also from the same nest. In total, 35,166 fixed records of the spatiotemporal movement data of those birds were obtained over the study period from May 28, 2017, to November 18, 2019. Subsequently, all GPS data were processed manually and plotted on the Google Earth map.

Results

Post-nesting dispersion before migration

From autumn 2017, the tracking data for seven Grey Herons were collected, but as time went on, it appears that less number of Grey Herons survived and in autumn 2019, only a single Grey Heron transmitted the signals from its tracker (Table 1). The Grey Heron, kb1715, did not transmit any data possibly from its early death or its loss of the tracker.

At 4–15 days before they left their colonies, the fledglings made short flights ranging from 50 to 750 m from their nests; the flight distance gradually increased day by day. Two fledglings from the Kamni Butakova Island have flown to the locations 6–26 km away from their colony until their full-scale post-nesting dispersion. During their post-nesting dispersion, all seven fledglings moved to the lower reaches of the Tumen River valley. Four of them, that is, fg1701, fg1706, kb1703, and kb1713, stayed at the borderland of North Korea, Russia, or China until their full-scale autumn migration (Figure 1). Their habitat areas were measured from 12.3 to 60.7 square km (40.4 square km on average), and they were composed of some fields and natural or artificial water bodies of the Tumen River basin. The other three, fg1702, fg1705, and kb1719, flew to locations higher in latitudes and far from their colonies and wandered there until their full-scale autumn migration (Figure 1); fg1705 moved to Arsenyev city in Primorskii Territory, Russia and fg1702 and kb1719 moved to Mudanjiang and Songyuan cities in Northeast China, respectively. Those areas are hundreds of kilometers away from their colonies. It appears that the habitat area utilized by any Grey Heron did not overlap with the habitat areas of the others (Figure 1).

Habitat usage in breeding sites

In 2018, even though two Grey Herons, fg1701 and fg1702, visited their native colony located on Furugelma Island several times, they did not breed there; fg1701 visited its native colony on June 5, 2018, for only 2–4 h and then moved to the border area of China and Russia where it had spent that summer in 2017 (Figure 1). In 2019, fg1702 spent most of the summertime on the Talmi Lake (12–15 km from its native colony) and only occasionally visited its native colony located on the Furugelma Island, and it has not bred until that time. kb1719 visited the breeding colony located on Furugelma Island from April 27 to 30 and sporadically in May and June 2018, but it never visited its native breeding colony located on Kamni Butakova Island. In 2019, kb1719 was bred successfully in the colony of Furugelma Island in which its nest was located on the outskirts of the colony.

Seasonal migration

The first autumn migration of the Grey Herons started from September 20 to October 29, 2017, and the duration and flight distance of the migration varied from 2 to 41 days and from 1583 to 4919 km, respectively. Four of the seven Grey Herons arrived in Thailand for wintering, and the other three wintered in China (Figure 2). Among them, the locational signals for four Grey Herons were short-lived and terminated during the wintering period. However, the other three Grey Herons survived that winter and migrated in spring 2018 for Far East Russia; two of them, fg1701 and fg1702, have wintered in Thailand for 6–7 months in 2017/2018 and started the flight for migration in May and completed in June 2018. The last one, kb1719, has spent the winter in China and started the migration on March 31 and completed on April 17, 2018 (Figure 3). The feeding areas exploited by the Grey Herons, fg1701, fg1702, and kb1719, during the breeding season in 2018–2019, partly coincided with those areas they had explored and used in 2017. However, during most of the breeding season in 2018, kb1719 moved to and stayed in new places near the Posiet village, the shore of Reid Pallada Bay,

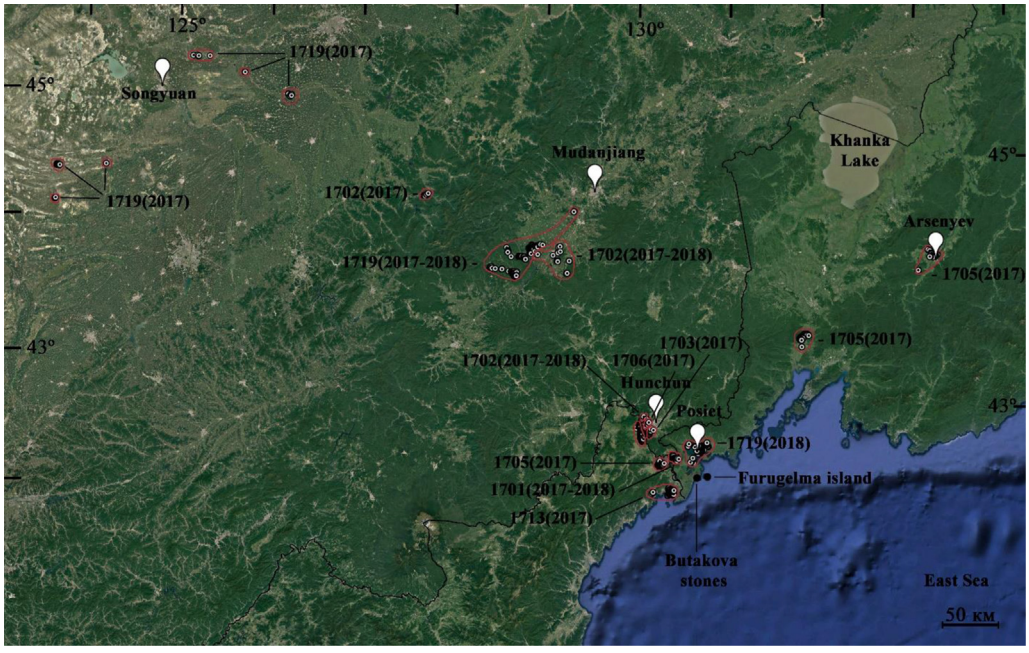

Figure 1. Habitat areas of the seven Grey Herons defined during their breeding seasons from 2017 to 2019.

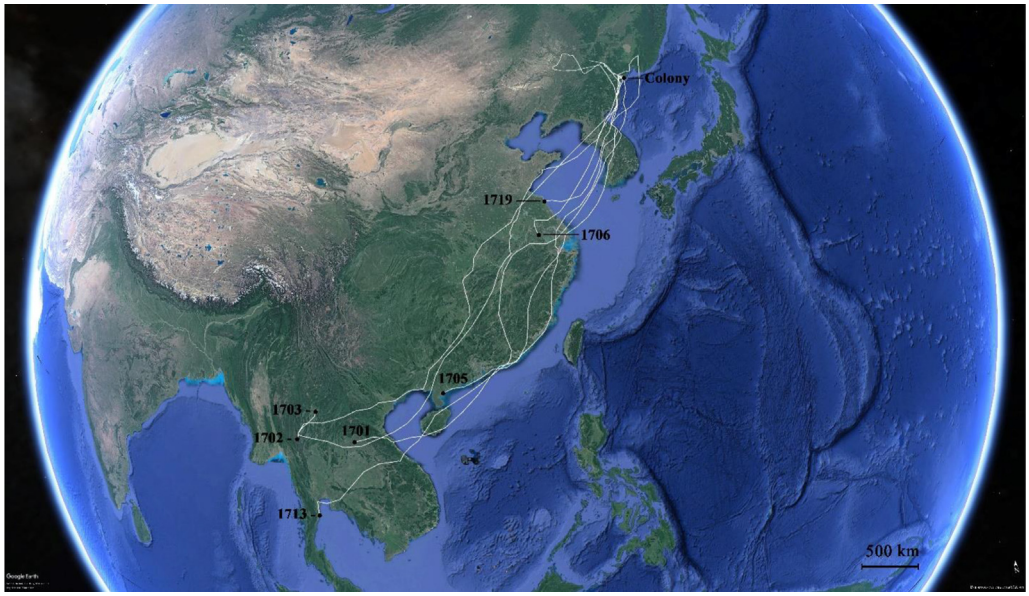

Figure 2. Southwest-bound migration routes of seven juvenile Grey Herons in autumn 2017.

Expedicia Bay, and Novgorodskaya Bay, close to its original colony located on Kamni Butakova Island (Figure 1).

The second autumn migration of fg1701 and kb1719 began on October 2 and October 24 in 2018, respectively (Figure 4). kb1719 migrated to the same wintering sites in the coastal area of East China as in 2017. However, in 2018, fg1701 wintered at the western coast of the Korean peninsula near Pyeongtaek, Gyeonggi province, while it had visited Thailand in 2017. It is thought that this bird has not been dead at least until the end of February 2019 because from that time its locations did not change at all. fg1702 had not transmitted any data during the autumn migration until November 2, 2018, when it was suddenly located near Chiang Mai, Thailand, and there it spent that winter (cool) season of 2018/2019 (Figure 4).

The second spring migration of fg1702 and kb1719 was done from April 10 to 15 and from March 16 to 18, 2019, respectively; kb1719 in Thailand started the migration about 1 month earlier than fg1702 in China. From October 11 to 13, 2019, for the third time, kb1719 migrated to the wintering area of East China as before (Table 1).

In total, we found 15 long-distance migration routes of the Grey Heron, ten for the autumn migration and five for the spring migration between breeding and wintering grounds. Most of these routes had detours and visits to the stopover sites in common. The directions of those routes were northeast or southwest-bound at large, and collectively they formed a kind of migration corridor spanning hundreds of kilometers in width. For migration, they mostly departed between 16:00 and 19:00 for night flight and during the day time they usually fed and took a rest on the grounds.

Some remarkable long-range non-stop voyages were recorded for fg1703 and kb1701. For the autumn migration, the longest non-stop flight was done by fg1703 in its first autumn migration; it flew 2590 km from the Yangtze River bank (near Ancin City, China) on October 28, 2017, and arrived at the Piing River valley (near Bang Pae City, Thailand) in 35 h (Figure 2). The longest non-stop flight for the spring migration was done by fg1701 in its first spring migration; it started on May 14, 2018, and flew 2004 km in 25 h (data not shown). Average travel speed of the Grey Herons varied from 62 to 80 km/h, but the ground speed calculated for the two consecutive coordinates recorded every 2 hours, varied from 43 to 93 km/h for Grey Herons. However, the actual speed, which is transmitted via the tracker every 2 h, was also recorded, and the highest was 107 km/h.

Migration pattern

With tracking data, we found that there were three patterns of migration for the Grey Herons captured in Far East Russia. The first one is a fast migration for which the bird flies quite a long distance with few stops, and this applies to the autumn migration of fg1702, fg1705, fg1706, and kb1719. For example, in autumn 2017, fg1702 migrated 4759 km to Chiangmai, Thailand in 176 h (Figure 5), fg1705 migrated 3735 km to the Leizhou Peninsula, China in 151 h, fg1706 migrated 1705 km to the Taikhu Lake in China in 45 h, and kb1719 migrated 1583 km to the Yellow Sea shore near Yancheng, China in 41 h (Table 1). The overall speed of these flights ranges from 24.7 to 38.6 km/h. In the same way, in autumn 2018, fg1701 and kb1719 migrated to the wintering places near Pyeongtaek, South Korea and Yancheong, China, respectively (Table 1). This kind of fast migration was reported in an adult Grey Heron that had been caught in 2014 at the Dongting Lake (Ye et al. 2018).

The second pattern is a delayed migration with an extended stay in the stopover sites; the birds flew some distance and had prolonged stopovers for a few weeks before resuming flights to finish their migration. For the autumn migration in 2017, the two Grey Herons, kb1703 and kb1713, flew thousands of kilometers and, on their way to the final wintering grounds, stopped in near the Chaokhu Lake (Hefei City, Anhui, China) and Yangtze River valley (Ancin City, China), respectively (Figure 6); kb1703 stayed for 33 days (from September 24, 2017, to October 27, 2017) and kb1713 stayed for 26 days (from October 4, 2017, to October 30, 2017) in their own stopover sites. In the same way, fg1701 also stopped in at the western shore of the Korean Peninsula during its southward migration after its flight of 858 km in 22 h and stayed there from October 17 to November 8, 2017, before its second phase of migration with the flight of 3392 km in 88 h to the Nong Khai province of Thailand. The spatiotemporal analysis showed the fast migration of fg1705 and kb1719 in comparison to the delayed migration of fg1701 and kb1703 during autumn 2017 (Figure 7), and it showed the delayed migration pattern of fg1701 and fg1702 in spring 2018. The third pattern is the migration accompanying frequent long-term stops, and it is more likely to be a summer wandering. This was shown in the spring migration of kb1719 in 2018 (Figure 8).

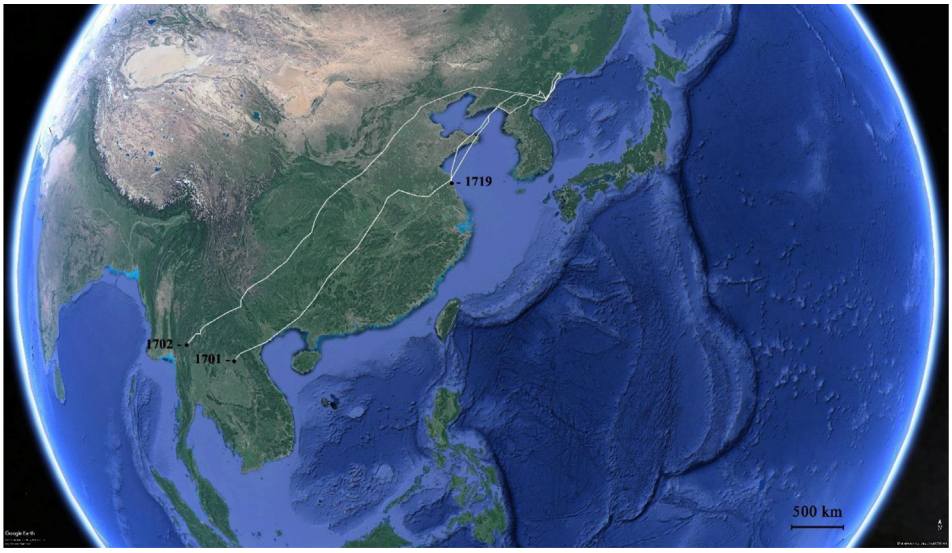

Figure 3. Northeast-bond migration routes of three Grey Herons in spring 2018.

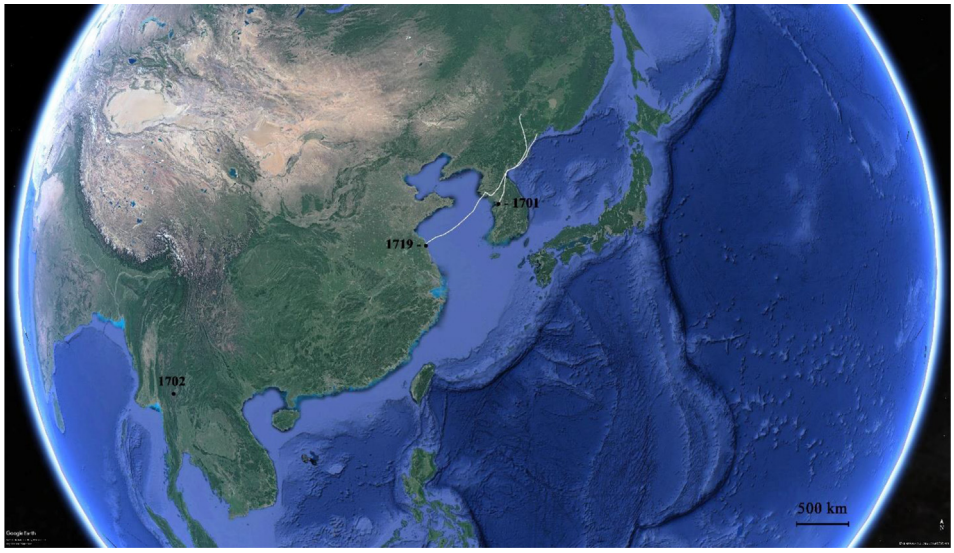

Figure 4. Southwest-bound migration routes of three Grey Herons in autumn 2018. The migration route of fg1702 could not be constructed due to the loss of signals during its migration for an unknown reason.

Discussion

For the first time, with GPS-GSM trackers, we were able to trace the migration routes of Grey Herons born in the breeding colonies of Peter the Great Bay accurately and locate the feeding and rest places during the post-nesting period and seasonal migrations. In this study, we proposed three different patterns of migration: fast, delayed, and wandering-like migrations. However, due to the limited number of observations, further investigation is needed to find out whether this classification is more generally applicable and which factors are related to those differences.

Seven fledglings of the Grey Herons left their colonies to search for another feeding grounds in their first year of age; three of them changed their feeding grounds several times and the other four kept the same feeding grounds until their first autumn migration (Figure 1). In relation to this, it has been also reported that some fledglings of the Grey Herons fed near their colony, but others made long flights around their colonies in search of better feeding places before the beginning of the autumn migration (Priclonskii et al. 2011). From the study on the Grey Herons conducted in 1960–1973 on the coast of the Khanka Lake in Primorskii Territory (Ilyichev 1978; Polivanov and Polivanova 1971), most of the fledglings of those colonies preferred feeding near the colonies within 26 km in radius before their autumn migration.

Even though the survival rate of the yearlings was low, all the surviving Grey Herons returned to their original feeding territories for the breeding season. In this study, none of the observed Grey Herons showed eastward flight for the autumn migration, even though it had been supposed that some Grey Herons would use the wintering grounds in Japan. Therefore, it seems that the Grey Herons on the island of the Peter the Great Bay prefer to use the southwest-bound migration routes.

Concerning the role of the Grey Heron in the transmission of avian influenza in East Asia, a highly pathogenic avian influenza virus, H5N8 subtype of clade 2.3.4.4b, has been isolated from the dead Grey Heron found in Korean Peninsula in January 2017, and, in terms of nucleotide similarity, some segmented genomes of it were very close to the viral strains identified in Western Siberia (Uvs-

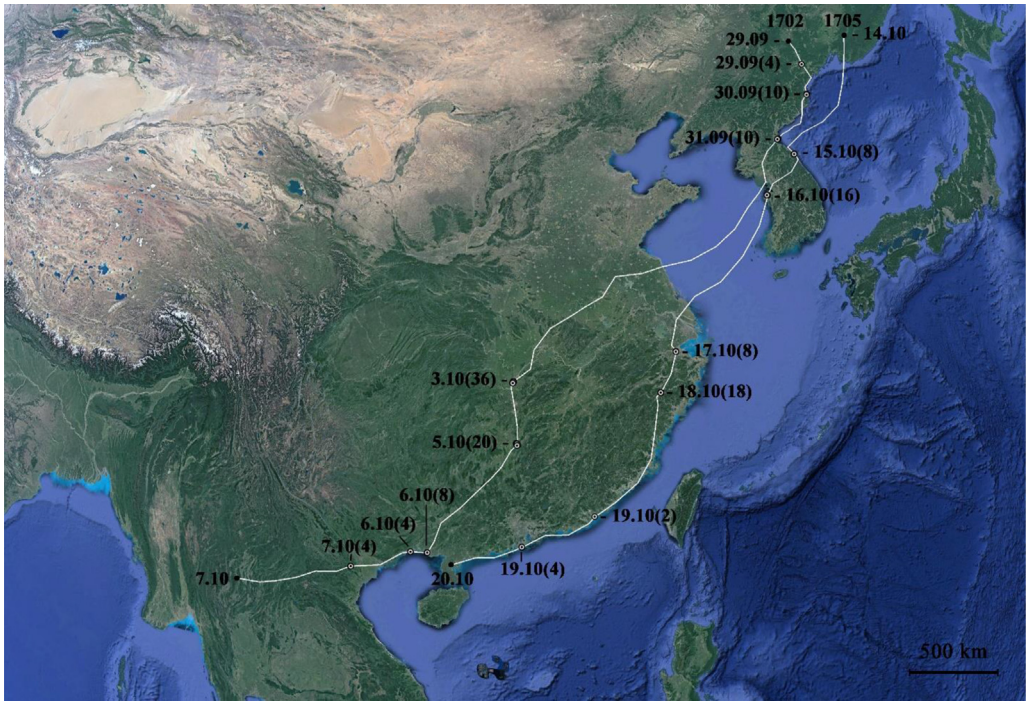

Figure 5. Southwest-bound migration routes with stopover sites of two juvenile Grey Herons (fg1702 and fg1705) representing fast migration in autumn 2017. The duration of their stay at the stopover sites was expressed in hours inside the brackets.

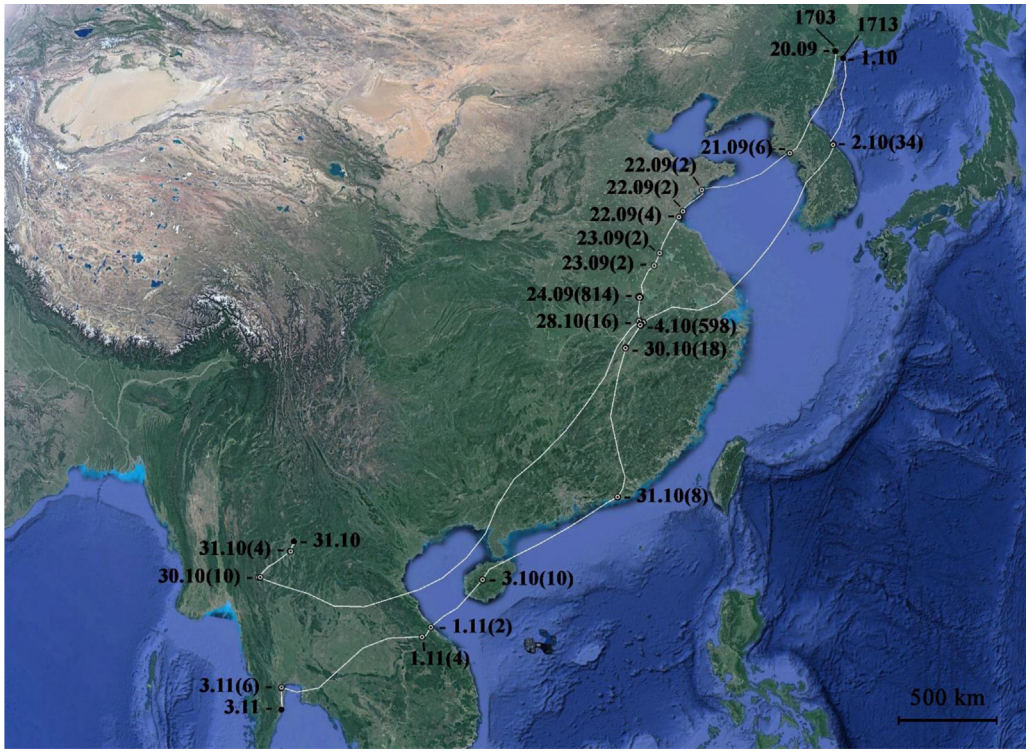

Figure 6. Southwest-bound migration routes with stopover sites of two juvenile Grey Herons, kb1703 and kb1713, representing delayed migration in autumn 2017. The duration of their stay at the stopover sites was expressed in hours inside the brackets.

Nuur Lake), China (Qinghai Lake), Europe, and India isolated in 2016–2017 (Woo et al. 2017). Hence, it is likely that somewhere in northern breeding sites, these new viruses might be generated and carried into Korean Peninsular by wild birds of unknown species. However, because most of the HPAI viruses had been isolated from the dead Grey Heron in many cases, it is more likely that the dead Grey Heron had been infected in the wintering grounds in South Korea. In relation to this, from the spring and autumn expedition on

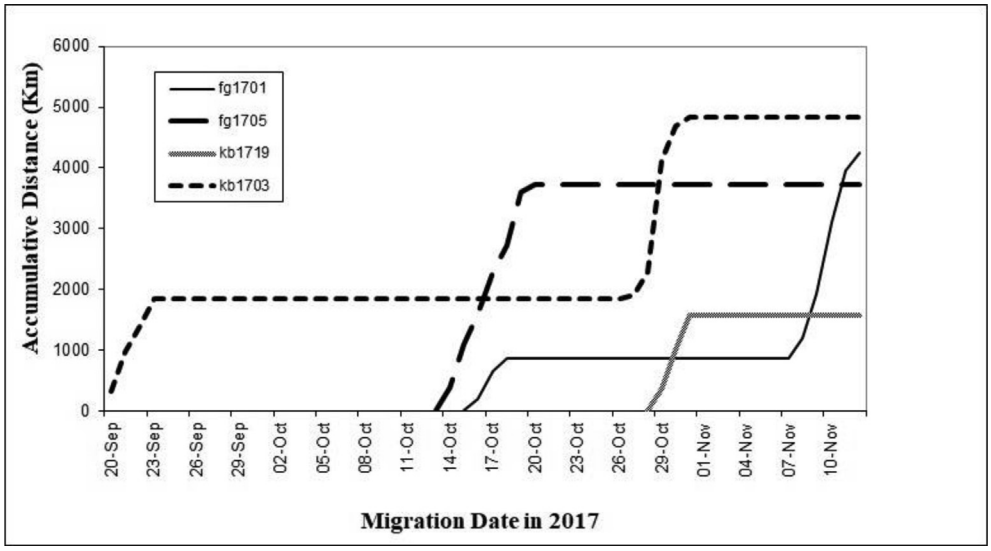

Figure 7. The accumulative distances flown at each calendar date during the autumn migration in 2017 by four Grey Herons of two different migration patterns.

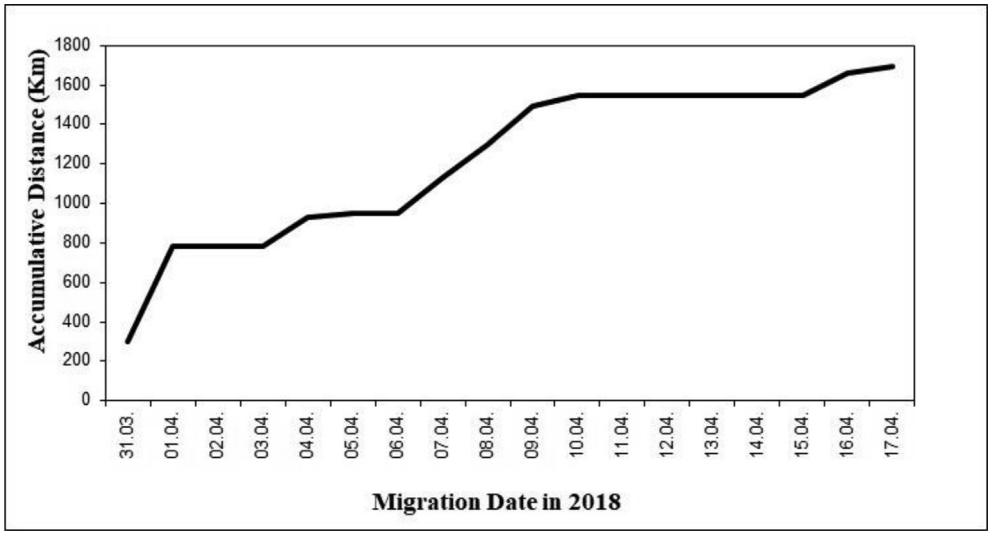

Figure 8. The accumulative distances flown at each calendar date during spring 2018 for the Grey Heron, kb1719, representing wandering-like migration.

the Khanka Lake and Peter Great's Bay in 1970, no antibody response against twelve avian influenza viruses of diverse subtypes could be found from the hemagglutination inhibition assay in the sera of the 12 Grey Herons, whereas in Baikal teal (*Anas Formosa*), Common snipe (*Gallinago gallinago*), Falcated duck (*Anas falcata*), Black-tailed gull (*Larus crassirostris*), the seroconversion to avian influenza viruses were confirmed (Slepuskin et al. 1972). This may explain that the Grey Heron seldom overcomes viral infection of HPAI. However, more studies on the possibilities of carrying avian influenza viruses by the Grey Heron need to be studied considering the importance of its long-range migration in Asia.

There have been repeated introductions of avian influenza into the Russian Far East. In April 2008, in the south of the Primorsky Krai, there were outbreaks of highly pathogenic avian influenza of subtype H5N1 of clade 2.3.2 in wild and domestic birds (Manin et al. 2010), and recently, in spring 2018, a low pathogenic avian influenza of subtype H9N2 occurred in a commercial poultry farm in Primorsky Krai (Marchenko 2019). In both of these cases, the wild birds were suspected as one of the possible sources of virus transmission to the poultry. Therefore, the studies on the migration routes and the usage of stopover sites of wild bird species, especially waterfowl species, would be helpful to evaluate the risk of viral introduction via wild birds. More specifically, the information about contact frequencies and the extent of the interaction among those species just before and during their seasonal migration would be of great interest to veterinary epidemiologists because the contagious period of the infected hosts is affected by all those factors.

In conclusion, ecological studies on wild bird species, which breed in northern regions including Far Eastern Russia and migrate southward, southeastward, or southwestward in autumn, would be very valuable sources to predict the spread of disease and to design avian influenza surveillance programs more precisely. In addition to that, the impact of those viruses on the lives of diverse wild bird

species might be estimated only with those results of the ecological studies.

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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