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Source: Zoological Science, 39(2) : 176-185

Published By: Zoological Society of Japan

URL: https://doi.org/10.2108/zs210071

ZOOLOGICAL SCIENCE **39**: 176–185 (2022)

Satellite Tracking of Migration Routes of the Eastern Buzzard (*Buteo japonicus*) in Japan Through Sakhalin

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We satellite-tracked the eastern buzzard (*Buteo japonicus*) wintering in Japan to delineate both northward and southward migration routes, destinations, and stopover behavior. Twenty-two buzzards were captured and fitted with functional platform transmitter terminals. For these buzzards that departed from the capture sites, we observed a total of 65 northward migrations during 2008–2016 and a total of 55 southward migrations during 2008–2015. In spring, the eastern buzzards migrated eastward along the Seto Inland Sea in the Chugoku region or further inland. In eastern Honshu, they followed two different routes. One was to Hokkaido via the Tsugaru Peninsula from central or northern central Honshu northward along the side of the Sea of Japan in northern Honshu. The other was to Hokkaido via the Shimokita Peninsula, mainly from the Pacific Ocean side of northern Honshu, moving eastward through central Honshu. Of the 17 birds tracked, 10 summered in Sakhalin, three in Hokkaido, three in northern Honshu, and one unknown. In autumn, the buzzards retraced their northward migration routes. Of the 14 birds that were tracked the entire southward migration, 13 (92%) returned to their respective capture sites. One juvenile wintered in an area different from the capture site. Our study contributes to a deeper understanding of the distribution of breeding and wintering grounds and the migration routes of *B. japonicus*. In addition, the information on migration obtained in this study can contribute toward appropriate environmental impact assessment for wind power facilities in Japan.

Key words: long-range movements, annual migration, migration pattern, wind farms, platform transmitter terminals

INTRODUCTION

Global warming and climate change are believed to be caused by greenhouse gases, and the introduction of next-generation energy that has lower carbon footprints is crucial (United Nations, 2015). One example of such energy is wind power, and the wind power generation system has been increasingly introduced worldwide (bp Statistical Review of World Energy, 2020; https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf). In Japan, the introduction of wind power generation facilities, mainly on land, has progressed rapidly since the 2000s, with a total installed capacity of approximately 4.37 million kW based on 2531 wind turbines in 2020 (Japan Wind Power Association; http://log.jwpa.jp/category/0000027525.html).

Although the carbon footprint of wind power would be low, it is not completely free from environmental impacts. One of the limitations is that flying animals such as birds and bats collide with windmills (bird strikes; Conkling et al., 2021). Many cases of bird strikes have been confirmed for wind turbines in Japan. The main victims are soaring raptors (Ura, 2015). This type of bird favors flying with wind support; therefore, it tends to occur around windmills that are built in areas with good wind conditions. Many soaring raptors are migratory and perform long-distance movements in spring and autumn. The migratory routes are located in areas with good wind conditions, where windmills are either already in place or could be constructed in the future. When a wind power facility of a certain scale is planned to be constructed,

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doi:10.2108/zs210071

an environmental impact assessment is conducted in Japan. On the other hand, there is not always enough information on the distribution and movement patterns of raptors, which should be taken into consideration for the assessment procedure. This lack of information may hinder the achievement of a proper and careful environmental assessment, and it is important to investigate and accumulate the ecological information of species in advance.

The eastern buzzard (*Buteo japonicus*) is a common migratory raptor species in eastern Asia. The buzzards favor soaring and gliding flights. The aspect ratio of their wings is small and their energy consumption during powered flight is relatively high (Agostini et al., 2015), and therefore wind support would be necessary for their migration. This species is distributed over central Siberia, southern Siberia, Mongolia, north-eastern China, and Japan (Gill et al., 2020). In Japan, the buzzards breed mainly in central to northern Honshu and central/southern Hokkaido. In western Honshu and Kyushu, they breed locally in limited regions. In winter, they are commonly observed along rivers, croplands of plains, and mountain regions; essentially, all over Japan, except for Okinawa prefecture and northern Hokkaido (Watanabe et al., 2017). This raptor species prefers soaring and collides with wind turbines, and in Japan, is the third most frequently colliding species in the Accipitridae, after the white-tailed sea eagle, *Haliaeetus albicilla*, and the black kite, *Milvus migrans* (Ura, 2015).

The migration of eastern buzzards has been observed in various parts of Japan. Owing to the efforts of many enthusiastic local observers, valuable information such as the number of migrating birds, migration direction, and timing has been accumulated (Kuno, 2013). These data are useful for understanding the average number and temporal variation of individuals observed at a certain point, differences in trends between survey points, and estimation of major migration routes. However, little is known regarding the entire migration route, destination, and ecology during migration at the individual level.

In this study, using satellites, we tracked the migration of eastern buzzards wintering in Japan. Satellite tracking is a useful research tool to show the migration routes and migration patterns of birds, such as raptors and waterfowl (Yamaguchi et al., 2008; Higuchi, 2012; Chen et al., 2016; Si et al., 2018). In particular, we characterized the annual patterns of long-range movements and delineated both northward and southward migration routes, destinations, and stopover behavior of the eastern buzzards using data from 17 satellite-tracked individuals from separate wintering localities. In addition, we describe the characteristic migration behavior observed only in juveniles. This basic migration study will provide useful information for the selection of construction sites for wind turbines and to assess the potential impact of wind turbines on the migration of this species.

MATERIALS AND METHODS

We captured a total of 22 eastern buzzards in the winters (November to March) of 2007 through 2009 at four sites in Japan: Hachirougata (39°56′N, 140°01′E), Akita prefecture, northern Honshu; Kahokugata (36°40′N, 136°40′E), Ishikawa prefecture, northwestern Honshu; Kisosaki (35°02′N, 136°46′E), Mie prefecture, central Honshu; and Aio (34°02′N, 131°24′E), Yamaguchi prefecture, western Honshu (Fig. 1). We attracted buzzards with caged mice and captured them harmlessly with a clap net that was flipped over the birds as they attacked the mice.

Seven buzzards were captured at Hachirougata (9 November 2007, 16–17 March 2008, 29–30 November 2008), four at Kahokugata (19–21 March 2009), four at Kisosaki (26–27 January 2008, 15–17 January 2009), and seven at Aio (22 February 2008, 28–31 January 2009) (see Supplementary Table S1). We measured several morphological traits (body weight, wing length, tail length, and tarsus length) and attached satellite transmitters (platform transmitter terminals [PTTs]) to the back of the birds with a harness system (for details see Yamaguchi et al., 2008). We used 20 solar-powered ARGOS PTTs (weighing 12 or 20 g, manufactured by North Star Science and Technology, Oakton, VA) and two ARGOS/GPS PTTs (weighing 22 g, manufactured by Microwave Telemetry, Inc., Columbia, MD). The ARGOS PTTs were programmed to transmit for 10 h, followed by 14 h periods without transmission. The ARGOS/GPS PTTs were programmed to record GPS locations at 0:00, 6:00, 9:00, 12:00, 15:00, and 18:00 h (Japan Standard Time [GMT+9:00]). These PTTs were designed to transmit for 2 to 5 years, depending on the conditions. The weight of the PTT plus harness system was 3–4% of the body weight of the birds, which was below the recommended weight of 4% of body weight (Kenward, 2001).

We recorded the date, time, and longitude and latitude of loca-

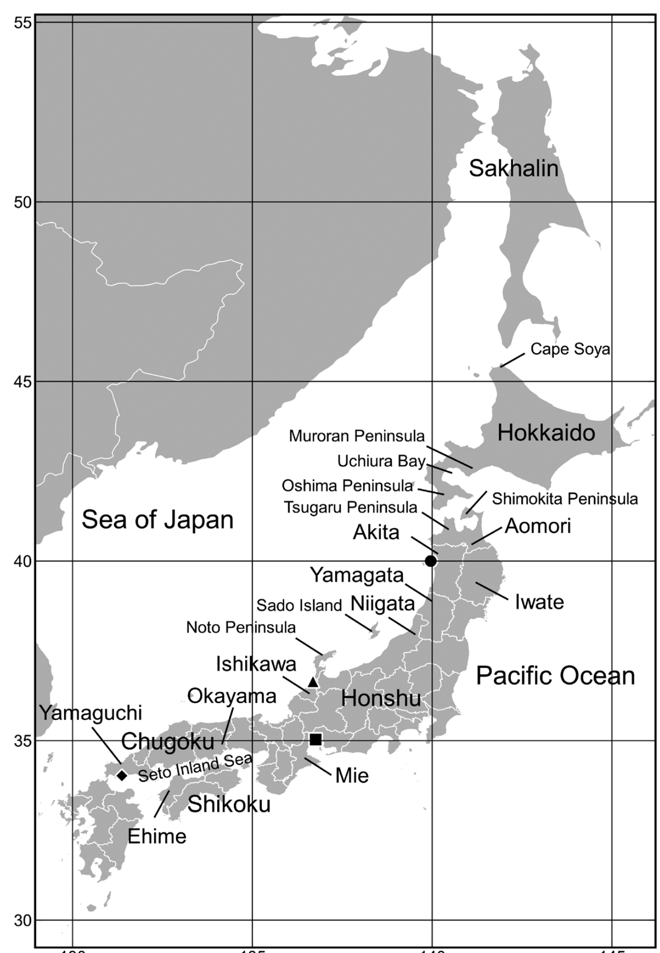

Fig. 1. Locations where eastern buzzards (*Buteo japonicus*) were captured and marked with satellite transmitters in Japan. Black filled figures indicate capture sites (●: Hachirougata, ▲: Kahokugata, ■: Kisosaki, ◆: Aio).

tions for each PTT using the Argos Data Collection and Location System (CLS, 2007). For the two ARGOS/GPS PTTs, we analyzed all GPS locational data, with a manufacturer-specified error of ± 22 m. For the 20 ARGOS PTTs, which provided less-accurate Doppler generated fixes, the locations were classified into seven categories (location classes, LCs) according to their precision. The standard deviation of positional error on the latitudinal and longitudinal axes was < 150 m for LC 3, 150–350 m for LC 2, 350–1000 m for LC 1, and > 1000 m for LC 0; the location accuracy for LCs A, B, and Z could not be determined (CLS, 2007). Before statistical analysis, we filtered the data using the Douglas Argos-Filter algorithm (Douglas et al., 2012). This program assessed the plausibility of every Argos location using two different methods based on (1) distances between consecutive locations and (2) the rates and bearing of consecutive movement vectors. After filtering, the worst location classes of LC 0, A, B, and Z were eliminated, whereas none of the LC 3, 2, and 1 locations were eliminated and all were retained for analysis.

We determined departure and arrival dates at the summering/wintering sites, the number and locations of stopover sites, and the duration of stay at the stopover sites. We defined the start of migration as leaving the summering or wintering site without returning to it, and the end as the arrival of the bird at a terminal site. We defined the terminal site as where the bird finished directional movement and stayed for more than a month. A stopover site was defined as an area used after departure from a wintering/summering site and where a bird did not travel in one particular direction (i.e., an area where a more or less random movement pattern was visually confirmed) for at least 24 h. If the interval to the next location was more than 24 hours, we did not classify it as a stopover site, because we could not distinguish between a bird that actually stayed at a single location and signals being scarce around the particular location. For Aio birds, the number of stopover sites was counted separately for ARGOS fitted birds and ARGOS/GPS fitted ones. Because some PTT data were intermittent, we could not always determine an individual's exact departure or arrival date. When the exact date of a migration movement could not be determined, we used the central date in the range of possible dates. If there were an uneven number of days in the potential range, we used the later of the two most central dates. We did not estimate arrival or departure dates if the potential range of dates was > 5 days. If there were multiple terminal sites, we used the date of arrival at the first destination as the arrival date. Similarly, we used the date of departure from the last destination as the departure date.

The distance travelled from one point to the next was calculated as the geodesic distance between two coordinates on the ellipsoid using Vincenty's inverse formula (Vincenty, 1975). The total distance covered on each journey is given by the sum of the segment distances.

We calculated the mean and standard deviation for the estimated duration of migration, cumulative tracking distance, number of stopover sites, and duration at stopover sites.

Fisher's exact probability test was used to analyze whether the frequency of individuals that migrated along either of the two main migration routes differed between age groups (adult or juvenile). A linear mixed model (LMM) was used to determine whether the latitudes of the summering sites differed among the wintering sites. The LMM was also used to examine whether the departure and arrival dates of spring migration were related to wintering sites and age (adult or juvenile). In these LMM analyses, individual identity and year were set as random effects. All statistical analyses were performed using R 3.6.1 (R Core Team, 2019).

RESULTS

PTT performance

We successfully tracked migration routes for 17 (five from Hachirougata, four from Kahokugata, two from Kisosaki, six from Aio) of the 22 buzzards to which we attached PTTs. Of the 17 buzzards, eight were juveniles (see Supplementary Table S1). Three PTTs stopped functioning for unknown reasons shortly after the birds were released. Two moved southward from the capture site in their wintering period; however, we were not able to track their northward migrations. From the 17 buzzards that departed the capture sites with functional PTTs, we observed a total of 65 northward migrations during 2008–2016 (Fig. 2A). We were also able to observe a total of 55 southward migrations during 2008–2015 (Fig. 2B).

Migration routes

Northward spring migration

In western Honshu, the eastern buzzards migrated eastward along the side of the Seto Inland Sea in the Chugoku region or further inland (Fig. 2A). In eastern Honshu, they followed two different routes. One was to Hokkaido via the Tsugaru Peninsula from central or northern central Honshu northward along the side of the Sea of Japan in northern Honshu. The other was to Hokkaido via the Shimokita Peninsula, mainly from the Pacific Ocean side of northern Honshu, moving eastward through central Honshu. Three birds terminated their migration in northern Honshu. Of the 14 birds that moved to Hokkaido, 10 (71%) migrated to Sakhalin, whereas three summered in Hokkaido. In Hokkaido, the birds that migrated to Sakhalin moved directly along the Oshima Peninsula or crossed Uchiura Bay (ca. 50 km maximum), and then went northward from western Hokkaido to Sakhalin via Cape Soya (70 km maximum). Two of the eight juveniles (AO-2 and KH-4) and one of the nine adults (KS-4) deviated from the above two general routes (see Supplementary Figure S1). There was no age (adult and young) difference in the proportion of individuals that deviated from the general routes (Fisher's exact probability test, $P > 0.99$).

We tracked the northward migration for two or more seasons for 11 buzzards (four adults and seven juveniles) (Fig. 3). Seven birds (63%; KS-1, AO-2, AO-3, AO-4, AO-5, AO-6, and AO-7) took a different route in some years from that followed in the first year in Honshu, whereas three birds from Hachirougata passed through almost the same routes every year. We observed that four (KS-1, AO-2, AO-5, and AO-6) of these seven birds took the alternate route of the two general routes. The remaining three birds (AO-3, AO-4, and AO-7) took only a partially different route in Honshu. For KH-1, the detailed northward migration routes after the second year in Honshu were unknown because the data were fragmentary.

Southward fall migration

The southward fall migration was tracked in 14 of the 17 birds. During the southward migration, the eastern buzzards retraced their northward migration route (Fig. 2B). Of the 14 birds, seven (50%; HR-3, HR-4, HR-5, HR-6, HR-7, KH-1, and KH-4) almost retraced their respective first northward routes throughout the entire southward migration (see Supplementary Figure S1). Of the remaining seven birds, three birds (AO-3, AO-4, and AO-7) took a slightly different route in central or western Honshu from their respective first

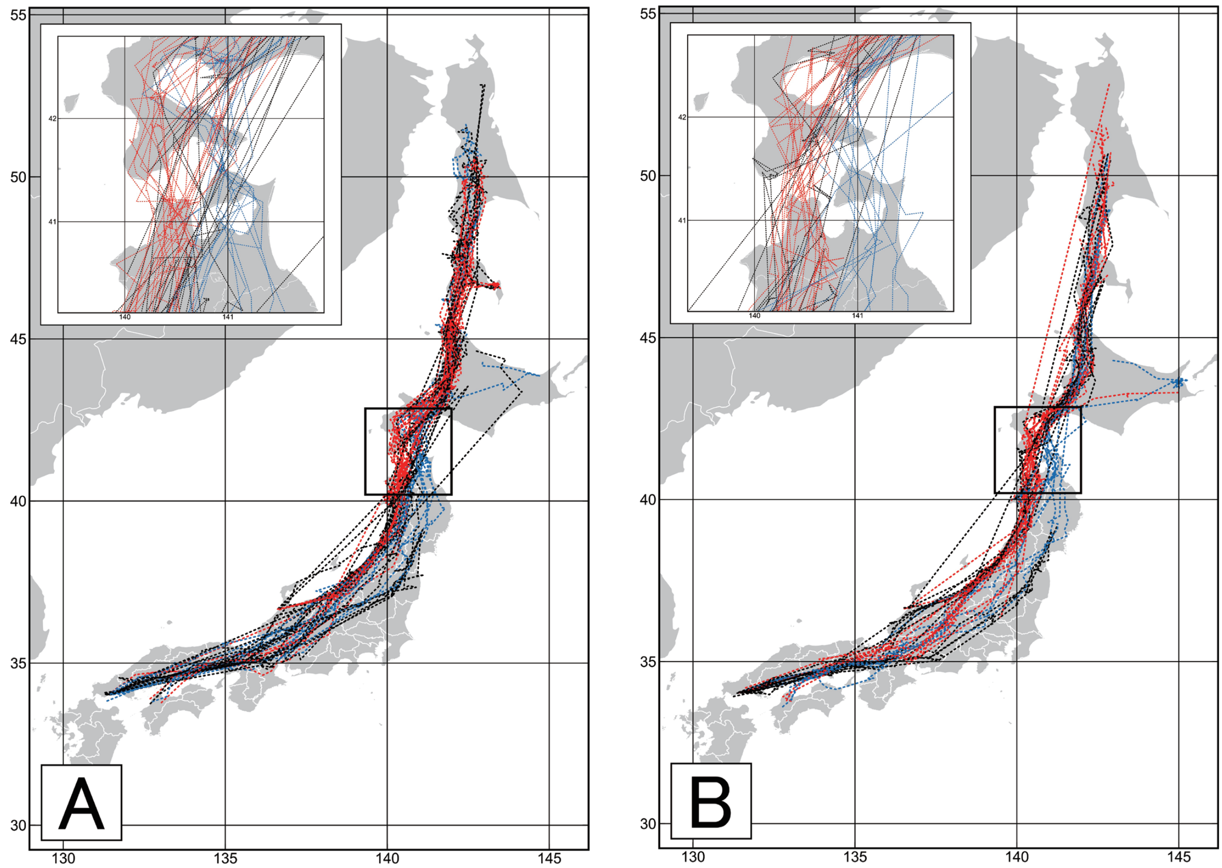

Fig. 2. Migration routes of 17 eastern buzzards (*Buteo japonicus*). **(A)** northward migration **(B)** southward migration. The red lines indicate the migration routes of the birds through the Tsugaru Peninsula. The blue lines indicate the migration routes of the birds through the Shimokita Peninsula. The black lines indicate the routes that could not be classified.

northward migrations (see Supplementary Figure S1). The other four birds (KS-1, AO-2, AO-5, and AO-6) took a different route from their respective first northward migrations in northern Honshu (see Supplementary Figure S1). Of the 11 birds that were tracked for the following year and beyond, four (36%; HR-4, KS-1, AO-4, and AO-7) passed through almost the same route every year (Fig. 4). Of the remaining seven birds, five birds (HR-3, HR-5, AO-3, AO-5, and AO-6) took partially different routes in Honshu and/or when crossing from Hokkaido to Honshu every year. For KH-1, the detailed southward migration routes after the second year were unknown because the data were fragmentary (Fig. 4). One bird (AO-2) passed through different routes in eastern Honshu every year (Fig. 4).

Terminal site

Summering site

Of the 17 birds tracked, 10 birds summered in Sakhalin, three in Hokkaido, and three in northern Honshu (Fig. 5). We were not able to identify the summering site of KS-4. The mean latitudes of the summering sites differed significantly among the wintering sites ($P < 0.01$: LMM). This difference was because the summering sites of the birds from the Aio wintering site were located more to the south than those of the birds from the northerly wintering sites (Kisosaki, Kahokugata, and Hachirougata) (Fig. 6). Of the 11 birds tracked for multiple years, only one juvenile (AO-2) changed its summering site substantially and another juvenile (AO-5) did so minimally. One adult (KH-1) and two juveniles (AO-2 and AO-7) used multiple areas as summering sites in the same year. AO-2 summered in southern Hokkaido, which is located approximately 260 km southwest of its first year's (2008) summering site, in 2009 and 2010. In 2011 and 2012, the birds summered approximately 10 km southeast of the second and third year sites. AO-5 summered approximately 50 km east of the usual summering site in 2016. KH-1 usually summered in southern Sakhalin. This bird also used an area located approximately 100 km southeast of the usual summering site in 2009. In 2014, this bird also used an area located approximately 600 km north of the usual summering site. AO-7 stayed in Niigata city for nearly 2 months before moving to Aomori prefecture in the first year (2009). However, the bird spent only 10 days at this location in the following year. Moreover, in the following year, the bird passed through this area without staying.

Wintering site

Of the 14 birds tracked during the entire southward migration, 13 (92%) birds, except for one juvenile (AO-2), returned to their respective capture site. However, it is not clear whether three birds (HR-6, HR-7, and KH-1) wintered there because the signal from these birds stopped shortly after reaching the capture site each year. AO-2 wintered in Ehime Prefecture, the only bird that wintered in an area dif-

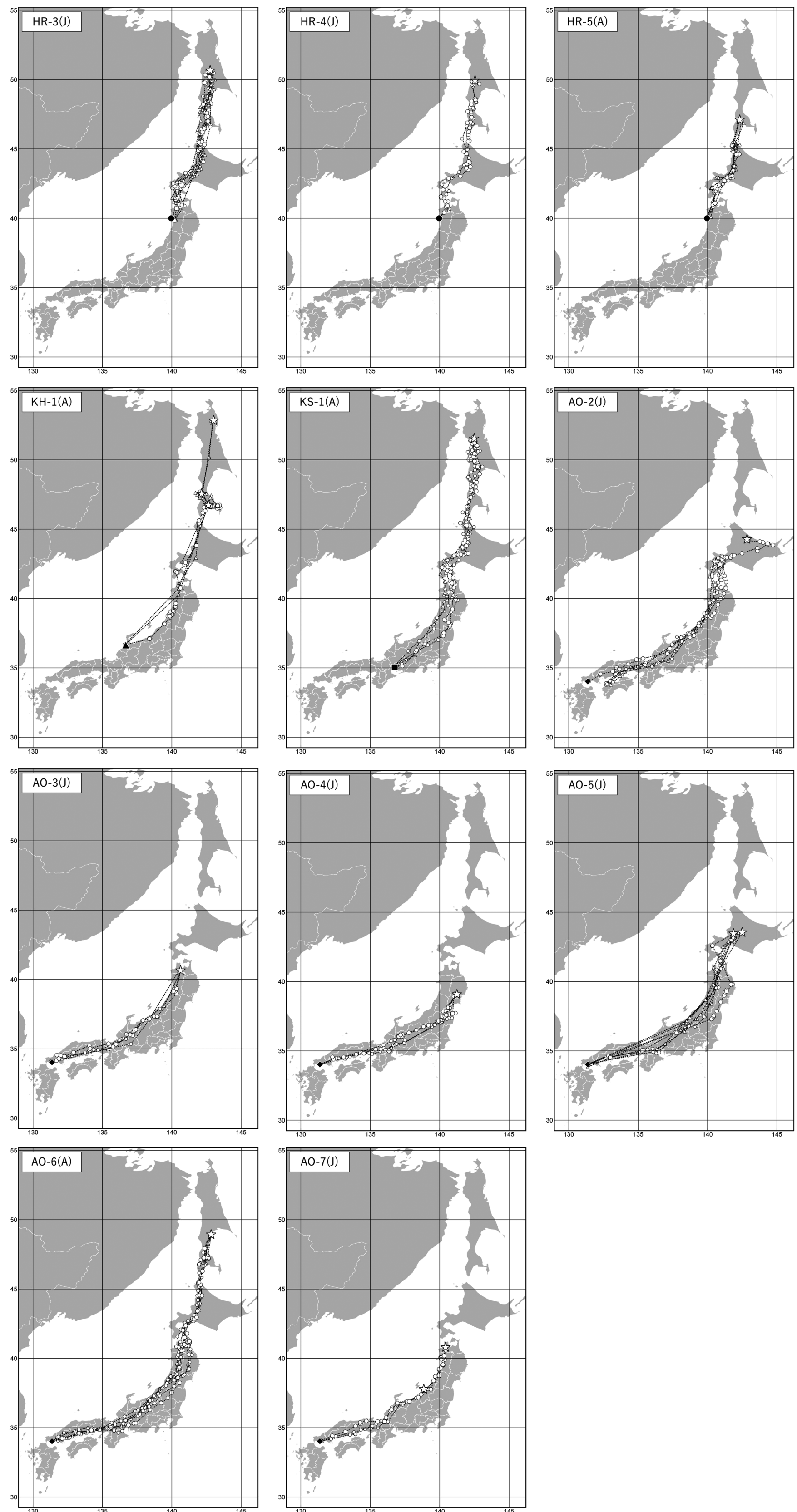

Fig. 3. Northward migration routes of 11 eastern buzzards (*Buteo japonicus*) for two or more years. Successive positions are connected by dotted lines. White circles indicate the data of a completed journey. White triangles indicate the data of an uncompleted journey. Mid-sized white circles and mid-sized white triangles indicate the data obtained in the first years. Large-sized, black-colored filled symbols indicate the wintering site of each bird. White stars indicate the summering sites of each bird.

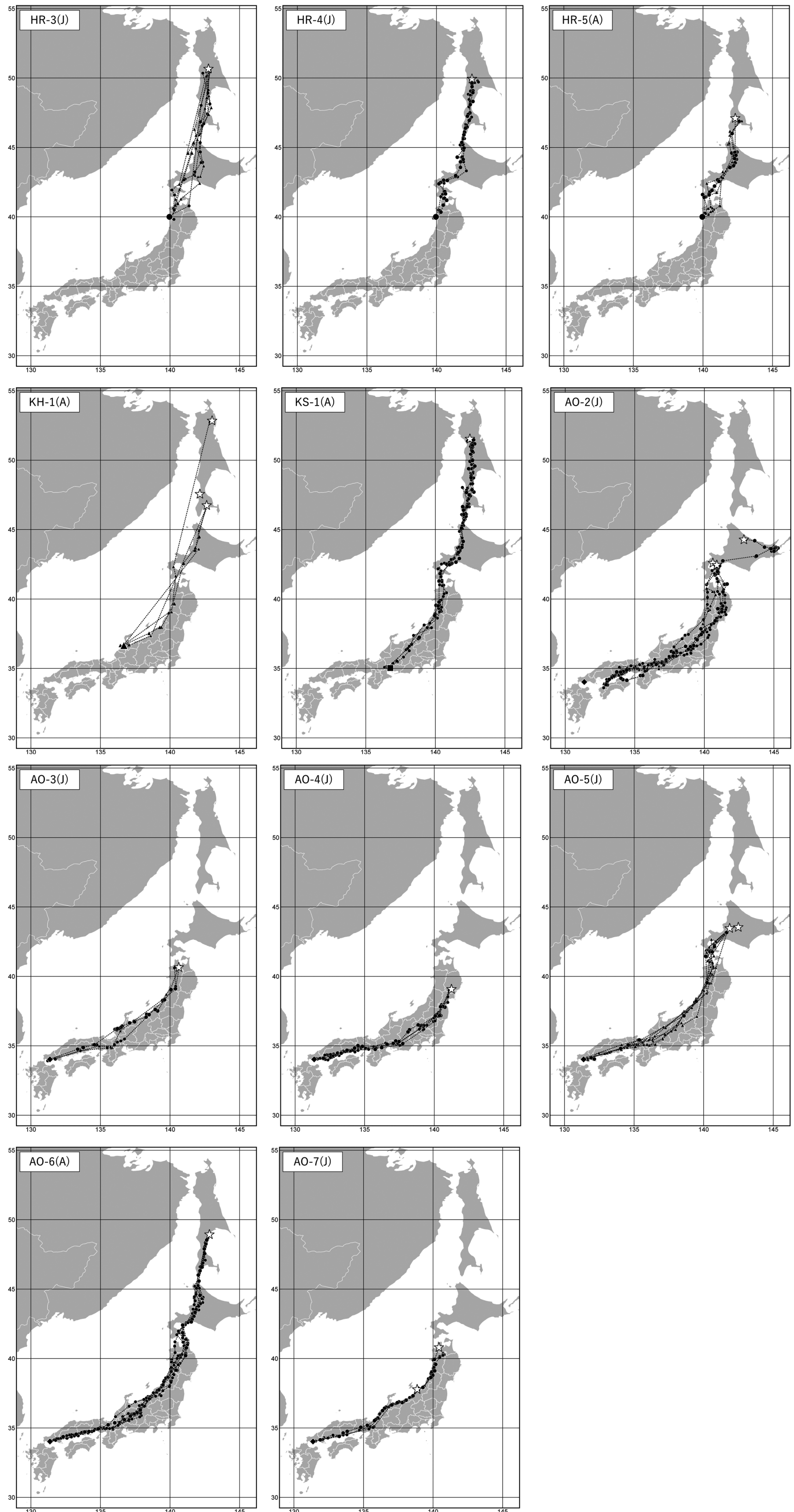

Fig. 4. Southward migration routes of 11 eastern buzzards (*Buteo japonicus*) for two or more years. Successive positions are connected by dotted lines. Black circles indicate the data of a completed journey. Black triangles indicate the data of an uncompleted journey. Mid-sized black circles and mid-sized black triangles indicate the data obtained in the first years. Large-sized, black-colored filled symbols indicate the wintering site of each bird. White stars indicate the summering sites of each bird.

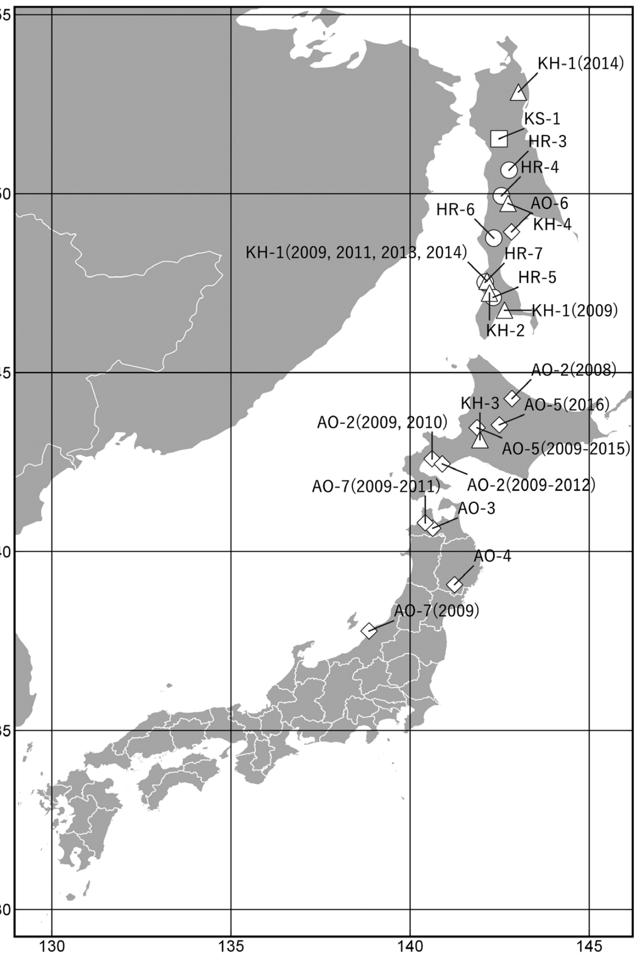

Fig. 5. Distribution of the summering sites of 17 eastern buzzards (*Buteo japonicus*). The symbols indicate the different capture sites (○: Hachirougata, △: Kahokugata, □: Kisosaki, ◇: Aio).

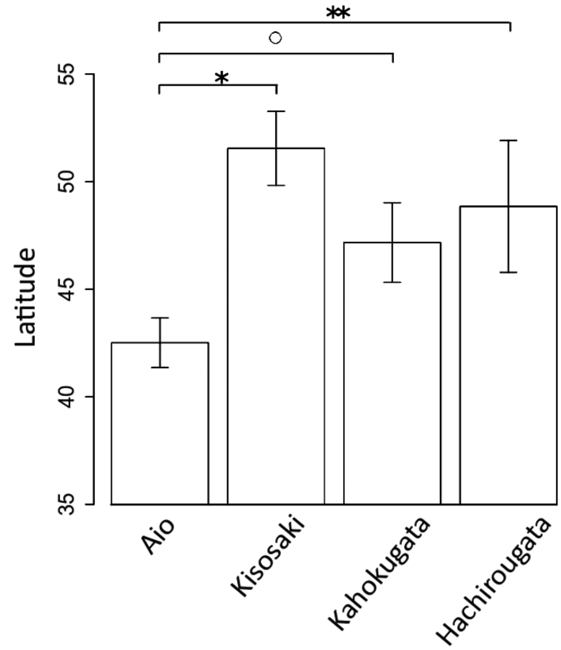

Fig. 6. Mean latitudes of the summering sites for the four wintering sites (Aio, Kisosaki, Kahokugata, and Hachirougata). The results of the Tukey-Kramer test are shown in the upper part of the graph. **: $P = 0.001$, *: $P = 0.016$, and °: $P = 0.053$.

ferent from the capture site.

Timing of migration

The estimated departure dates from wintering sites and the arrival dates at summering sites ranged from 5 March to 7 May and from 23 March to 19 May, respectively. Although juveniles departed their wintering grounds later than adults from the same area in the same year, there was no significant age difference in the departure date ($P = 0.29$, LMM). The departure date did not significantly differ among the wintering sites ($P = 0.16$, LMM), although individuals that wintered at more northeasterly sites (Hachirougata, Kahokugata, and Kisosaki) tended to depart later than those that wintered at the most southwesterly site (Aio). Neither age nor wintering site affected the date of arrival to the summering sites ($P = 0.94$ for age, $P = 0.45$ for wintering site (LMM). The estimated duration of the northward migration ranged 3.9 to 31.0 (16.1 ± 7.1 SD) days ($n = 31$) after the start of migration, and the cumulative tracking distance on northward migration ranged from 872 to 2751 (1641 ± 537 SD) km ($n = 39$).

The estimated departure dates from the summering sites and the arrival dates at the wintering sites ranged from 9 September to 30 December and from 1 October to 7 February of the following year, respectively. We did not perform statistical analyses to test the difference between age or among wintering sites regarding the schedule of autumn migrations because of the small sample size ($n = 3$ [Hachirougata], $n = 0$ [Kahokugata], $n = 2$ [Kisosaki], $n = 10$ [Aio]) for departure from summering sites; $n = 25$ ($n = 4$ [Hachirougata], $n = 0$ [Kahokugata], $n = 2$ [Kisosaki], $n = 19$ [Aio]) for arrival at the wintering sites). The estimated duration of southward migration ranged from 9.8 to 55.4 (28.8 ± 12.6) days ($n = 13$) after the start of migration. The cumulative tracking distance on southward migration ranged from 1173 to 2721 (1721 ± 520) km ($n = 29$).

Number and duration of stopover sites

We were able to observe 94 (northward 49, southward 45) stopover sites from 14 birds (see Supplementary Table S2), more than half (60 [64%]) of which were from two birds fitted with GPS transmitters (AO-6 and AO-7). The mean number of stopover sites on the northward migration was 0.2 ± 0.4 ($n = 9$), 1.0 ± 0.8 ($n = 4$), 1.0 ± 0.0 ($n = 3$), and 1.3 ± 1.4 [$n = 23$; 0.3 ± 0.4 (ARGOS, $n = 13$), 2.8 ± 0.9 (ARGOS/GPS, $n = 10$)] for birds from Hachirougata, Kahokugata, Kisosaki, and Aio, respectively. The mean number of stopover sites on the southward migration was 0.6 ± 0.8 ($n = 5$), 0.0 ($n = 1$), 1.0 ± 1.0 ($n = 3$), and 1.9 ± 1.9 [$n = 20$; 0.4 ± 0.5 (ARGOS, $n = 11$), 3.5 ± 1.7 (ARGOS/GPS, $n = 9$)] for birds from Hachirougata, Kahokugata, Kisosaki, and Aio, respectively. The mean duration at stopover sites on the northward migration was 3.2 ± 1.6 ($n = 5$), 4.0 ± 1.8 ($n = 5$), 4.3 ± 2.1 ($n = 4$), and 4.2 ± 3.1 ($n = 35$) days for birds from Hachirougata, Kahokugata, Kisosaki, and Aio, respectively. The mean duration at stopover sites on the southward migration was 2.5 ± 1.3 (n = 4), 5.1 ± 2.4 (n = 3), and 4.5 ± 4.7 (n = 38) days for birds from Hachirougata, Kisosaki, and Aio, respectively.

DISCUSSION

In this study, we performed satellite tracking of 17 eastern buzzards from western Japan and clarified their migration routes and movement patterns across a significant portion of the Japanese archipelago. In addition, we succeeded in identifying the summering sites of individuals wintering in western Japan. To our knowledge, this is the first report of the migration of the eastern buzzard, *B. japonicus*. Although the eastern buzzard has been treated as a subspecies of the common buzzard (*Buteo buteo*), *B. japonicus* was recently found to be a separate species using molecular phylogenetic analysis (Haring et al., 1999; Riesing et al., 2003; Kruckenhauser et al., 2004; Lerner et al., 2008). Moreover, recent studies suggest that the phylogenetic relationship among *Buteo* species in East Asia is complex: *B. japonicus* lineages are intermingled with Himalayan buzzard, *Buteo refectus,* and upland buzzard, *Buteo hemilasius* (Kruckenhauser et al., 2004), and different lineages have been confirmed to exist within *B. japonicus* (Kruchenhauser et al., 2004; Nagai et al., 2019, 2020). In order to devise a reasonable classification, it will be necessary to accumulate more detailed information on the morphology, distribution, and migratory behavior, as well as genetic information, of the genus *Buteo* species in East Asia. The results obtained in this study contribute to a deeper understanding of the distribution of breeding and wintering grounds and the migration routes of *B. japonicus*. Moreover, the information on migration obtained in this study would contribute to planning where to build wind power facilities, and to making careful environmental impact assessments for constructing onshore wind power facilities in Japan.

Migration routes, migration schedule, and terminal sites

The main migratory route of the tracked individuals, extending from Honshu to Hokkaido and Sakhalin, branched into multiple routes between central Honshu and the northern tip of Honshu. However, long migratory routes existed from Niigata prefecture to the Japan Sea coast northward, and from the Oshima Peninsula to northwestern Hokkaido. The eastern buzzards winter in western Japan, and at least among the individuals we tracked, they do not migrate to the continent but stay within the Japanese archipelago and Sakhalin, which are separated from the continent by the Sea of Japan. This finding is important for understanding the spatial distribution of *B. japonicus*. The actual spatial distribution of *B. japonicus*, which is distinct from that of *B. buteo*, is not fully understood and requires further research in East Asia.

The eastern buzzards we tracked consecutively migrated between specific wintering and summering areas each year, with a few exceptions. The present findings that wintering and breeding sites, and the migratory routes between them, are fixed to some extent at the individual level are consistent with reports of previous studies on other soaring raptors (red-tailed hawk, *Buteo jamaicensis* (McCrary et al., 2019); crested honey buzzard, *Pernis ptilorhynchus* (Shiu et al., 2006); and grey-faced buzzard, *Butastur indicus* (Shiu et al., 2006)).

At the population level, we did not find a clear one-to-one relationship between the wintering and summering sites. All the birds from Hachirougata summered in Sakhalin; however, summering sites were scattered from the southern to the central part of Sakhalin. Using satellite tracking, the phenomenon of a one-to-one relationship has not been shown in previous studies on other bird species either (Yamaguchi et al., 2008; Shimada et al., 2014; Chen et al., 2016), and may therefore not be a common feature for migratory birds. However, the summering sites of birds that wintered at Aio were significantly further to the south than those of the birds that wintered at northerly sites. The time and distance that this species migrates might be somewhat constant, and the breeding areas of individuals wintering in the south may be located relatively farther south.

Juvenile characteristics

We found a certain degree of variation in the migratory patterns of some juveniles. A larger variability in the migration direction of juveniles than that of adults is a general pattern found in other migratory raptors (e.g., European honey buzzard, *Pernis apivorus*; Thorup et al., 2003). Juveniles of a species in which adults and young birds migrate at different timing are unable to learn appropriate migration routes from adults (Hake et al., 2003). Young soaring raptors do not compensate adequately for wind-induced shifts in their migration routes and, as a result, their destinations may vary greatly (Vansteelant et al., 2017; Vansteelant and Agostini, 2021). In this study, one juvenile (AO-2) summered in northeastern Hokkaido in the first year, but after the second year, the bird summered in southern Hokkaido. The more direct and shorter distance route during the second southward migration indicates that the bird was able to correct its course with acquired experience. One juvenile (KH-4) moved a total of approximately 200 km over the Sea of Japan (see Supplementary Figure S1). The avoidance of geographical barriers, such as water bodies and deserts, is considered a general feature in other migratory soaring raptors (Alerstam, 2001; Panuccio et al., 2021). The movement of this juvenile bird may reflect the immaturity of its navigation abilities.

Although not statistically significant, juveniles tended to depart later than adults tracked from the same area in their first northward migrations. In other *Buteo* species, later departure of immatures relative to adult birds has been confirmed in spring migration (Broekhuysen and Siegfried, 1969; Schmitt et al., 1980; Christensen et al., 1981). This may reflect an age-related migration strategy, that is, if immature individuals do not breed, arriving later than adults may be unimportant (Gorney and Yom-Tov, 1994). Alternatively, juveniles may need more time to store the energy to start migration than adults due to their lack of experience.

Implication for bird strikes to wind turbines

In this study, we revealed the major migration routes of the eastern buzzards traversing Honshu and Hokkaido in spring and autumn. The impact of wind farms along these main migratory routes on this species needs to be carefully evaluated. In Honshu, a considerable number of the buzzards tracked moved along the coast of the Japan Sea. A large number of wind power facilities have already been constructed along the coast of the Japan Sea in the Tohoku region (http://agora.ex.nii.ac.jp/earthquake/201103-eastjapan/energy/electrical-japan/type/7.html.ja), suggesting an overlap with the migration route of the eastern buzzards. If too many wind farms are located along important migration routes, the cumulative loss in time and energy of migrants from detouring around wind turbines is a concern (Drewitt and Langston, 2006). In particular, spring migration is followed by the important life-history event of breeding, and failure to arrive at the breeding ground at the appropriate time, and not having sufficient energy at the time of arrival, may negatively affect reproductive performance (Saino et al., 2017). The extent to which the cumulative effect of detours around wind turbines is acceptable in terms of maintaining the population of this species should be evaluated quantitatively. In Hokkaido, the main route from the Oshima Peninsula to Cape Soya was confirmed. In addition, the migration routes of many individuals were extended to Sakhalin. These routes included the Tsugaru Strait (ca. 65 km maximum) and Soya Strait (ca. 70 km maximum). Most individuals pass through the peninsula and the capes facing the straits. Wind turbines that have been built or are planned to be built in such “bottleneck” regions of migration routes require very careful consideration of the risk of collision. The impact of a wind turbine built in a critical place (such as the bottleneck regions of main migration routes) which many buzzards pass through would not be confined to the local areas, but also could extend to distant regions.

Currently, there is no concern regarding the decline in the population of eastern buzzards in Japan, except for the subspecies *B. j. toyoshimai*, which is distributed to the Ogasawara Islands (only *B. j. toyoshimai* is listed in the Japanese Red List as ‘EN’). This might suggest that the eastern buzzard, the third most frequently colliding species in the Accipitridae (Ura, 2015), is still not affected enough to show changes in the population number caused by colliding with wind turbines. If more wind power facilities are placed in the critical areas of the major migration routes of this species, it may have non-negligible impacts in the future. The Japanese government aims for wind power to account for approximately 1.7% of its electricity mix by 2030. Currently, wind power accounts for 34% of the 2030 forecast, and the number of wind power facilities is expected to increase significantly in the future in Japan (Ministry of Economy, Trade and Industry 2018, https://www.enecho.meti.go.jp/about/special/johoteikyo/huryokuhatuden.html). The specific migration routes of eastern buzzards obtained in this study will provide essential basic information for planning the location of future wind power facilities to be constructed and for conducting appropriate environmental assessments of the planned areas. It is also necessary to conduct more basic research to accumulate information on the migration of other bird species that may be negatively affected by bird collisions.

ACKNOWLEDGMENTS

We thank R. Harada, T. Nakagawa, N. Shigeri, Y. Kondo, and H. Amano for their assistance in the field. This study was funded by the Ministry of the Environment, Japan.

COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

NH wrote the manuscript and prepared the figures. NMY performed the statistical analysis. EH, FN, KU and KT conducted a field survey. HH conceived and designed the study.

SUPPLEMENTARY MATERIALS

Supplementary materials for this article are available online. (URL: https://doi.org/10.2108/zs210071)

Supplementary Figure S1. Migration routes of 17 eastern buzzards (*Buteo japonicus*).

Supplementary Table S1. Individual information and tracking data for 22 eastern buzzards (*Buteo japonicus*) fitted with platform transmitter terminals (PTTs) at four wintering sites in Japan.

Supplementary Table S2. Locations of stopover sites used by 14 eastern buzzards (*Buteo japonicus*) during the northward and southward migrations.

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(Received June 21, 2021 / Accepted December 8, 2021 /
Published online February 17, 2022)