Migration routes of satellite-tracked Rough-legged Buzzards from Japan: the relationship between movement patterns and snow cover

Noriyuki M. YAMAGUCHI[1,#], Emiko HIRAOKA[2], Naoya HIJIKATA[3] and Hiroyoshi HIGUCHI[3]

[1] Graduate School of Fisheries and Environmental Sciences, Nagasaki University, Bunkyo-machi 1–14, Nagasaki-shi, Nagasaki 852–8521, Japan
[2] Ohzono-machi 9–11–1409, Nagasaki-shi, Nagasaki 852–8062, Japan
[3] Graduate School of Media and Governance, Keio University SFC, Endo 5322, Fujisawa-shi, Kanagawa 252–0882, Japan

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Abstract The Rough-legged Buzzard *Buteo lagopus* is a Holarctic species that breeds in the Arctic and subarctic regions and winters in a broad range from 40° to 55°N. In Japan, this species is typically a rare winter visitor, but in January 2008 there was an unprecedented influx and 350–400 individuals were observed in western and central Japan. Winter irruptions of this species are considered to be caused by low temperatures and increased snow cover. Here, we describe the distribution of snow cover in mainland Asia leading up to the irruption into Japan. We predicted that movement patterns during spring migration would also be influenced by snow cover. We satellite-tracked four Rough-legged Buzzards from Japan, to show their spring migration routes, and examined the relationship between their spring movement patterns and changes in snow cover along their route. There were two spring migration routes from Japan, which varied with wintering sites. One route led up to the Amur River basin bordering China and Russia. The other extended northwards, reaching the lowlands of the western Chukotka Autonomous Okrug in North-eastern Russia. The bird following the latter route was tracked for two consecutive years and was found using the same summering site in 2009. Shortly before the irruptive movements into Japan, most of north-eastern China and eastern Russia were covered with snow, suggesting that unusually severe weather conditions caused the irruptive movements. The northward movements of one bird tracked to Russia generally matched the northward progression of snowmelt.

Migratory birds must cope with various weather conditions while travelling (Richardson 1978; Richardson 1990a; Richardson 1990b; Richardson 1991; Liechti 2006; Nourani and Yamaguchi 2017). Although tailwinds and thermals enable some migratory birds to make long distance flights without refuelling (e.g. Gill et al. 2009; Chevallier et al. 2010; Yamaguchi et al. 2012; Nourani et al. 2016), headwinds, precipitation, and storms can slow migrating birds. Snow cover is an additional constraint for migratory birds foraging for food on the ground (Wege & Raveling 1983; Hupp et al. 2001), because

it hides food items such as vegetation and small mammals. Therefore, one would expect a correlation between the temporal variation in snow cover and the movement patterns of the migratory birds, although no such correlation study has been conducted yet on a large scale.

The Rough-legged Buzzard *Buteo lagopus* is a Holarctic predator that normally breeds in the arctic and subarctic regions of Eurasia and North America and winters between 40°N and 55°N (Cramp & Simmons 1980; Mindell & White 1988; Virkkala 1992; Whitaker et al. 1996; Potapov 1997). Its prey consists mainly of voles and lemmings (Cramp & Simmons 1980; Potapov 1988; but see Pokrovsky et al. 2015). This raptor makes nomadic movements

and their spring irruptions correlate with the cyclical availability of rodents in their breeding areas (Galushin 1974; Cramp & Simmons 1980; Potapov 1997). Winter irruptions are induced by low temperatures and snow (Dobler et al. 1991; Knaus 2012), probably because snow hides the small mammals that are their main food items. Snow cover influences where this raptor species concentrates its search for food, because they usually hunt in open habitats and because voles are considered to be active beneath snow cover, thereby reducing prey availability (Sonerud 1986). Given these factors, the movement patterns of the Rough-legged Buzzard during spring migration may also be affected by the northward progression of snow melt, although the migration routes and their relationship with snow cover during winter and spring are not fully understood.

In Japan, this species is a rare winter visitor, seen mainly in Hokkaido and northern Honshu (Morioka et al. 1995). However, in January 2008, 350–400 individuals were observed in western and central Japan (Kuno 2013). Here, we describe the rapid temporal changes in snow cover in mainland Asia leading up to the irruption to Japan and report on our investigation into the link between the rapid extension of snow cover and the observed migration. We then describe the spring migration routes of satellite-tracked Rough-legged Buzzards from Japan after the irruption; one of these birds was tracked for two consecutive spring migrations. We also examined the relationship between the seasonal movement patterns of the tracked bird and the northward progression of melting snow along its migration routes.

MATERIALS AND METHODS

1) Satellite-tracking

In the winter of 2008 we captured four Rough-legged Buzzards in Japan and tracked them by means of satellite transmitters during the subsequent spring and autumn migrations. We captured and marked three buzzards at Kisozaki (35°02′N, 136°45′E), Mie Prefecture (N=3, unknown sex, juveniles) on 26 and 27 January 2008, and a fourth bird on 10 March 2008 at Aio (34°02′N, 131°24′E), Yamaguchi Prefecture (N=1, unknown sex, juvenile). We attracted buzzards with caged mice and captured them with a clap net that was flipped over the birds as they attacked the mice. We used solar-powered Platform Transmitter Terminals (PTTs; North Star Science and Technology, Inc., King George, VA, USA), which we attached to the backs of the birds with Teflon-treated ribbons (Yamaguchi & Higuchi 2008; Yamaguchi et al. 2010). The weight of the PTTs (12 or 20 g) plus the harness material was 1.5–2.6% of the body mass of the marked birds. The PTTs transmitted for 10 h, followed by a 14-h period without transmission.

We recorded the date, time, and longitude and latitude of locations for each PTT using the Argos Data Collection and Location System (CLS 2016). The locations were classified into seven categories (Location Classes; LCs) according to their precision. The estimated errors for LCs 3, 2, 1, and 0 were <250 m, 250–500 m, 500–1500 m, and >1500 m, respectively. The error had no upper limit for LC 0, although testing of stationary PTTs indicates that it is usually <5 km (Brothers et al. 1998; Britten et al. 1999; Hays et al. 2001). Other LCs (LCs A, B, and Z) were considered inaccurate, because they had fewer satellite overpasses. We used locations with LCs 3, 2, 1, 0 for the analyses. We used only one location per transmission cycle to represent an individual's daily position and to reduce spatiotemporal autocorrelations. If we obtained multiple locations during a transmission cycle, we used only the best location as identified by a computer program provided by Douglas (2006). 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.

2) Data analysis

We examined the distribution of snow cover in the days prior to the irruption (1 January 2008) and the relationship between the migration patterns of a marked bird and the northward progression of melting snow along the spring migration route. We obtained daily Northern Hemisphere snow and ice data from the National Snow and Ice Data Center's Interactive Multisensor Snow and Ice Mapping System (IMS) (National Ice Center 2008), which provides Northern Hemisphere snow and ice maps from February 1997 onward. These maps are derived from a variety of data products including satellite imagery and in situ data. The data were available in ASCII text and GeoTIFF formats in 1-, 4-, and 24-km resolutions. IMS estimates snow covered area based primary on visible and infrared imagery from satellites (Ramsay 2000; National Ice Center 2008). Snow depth is not estimated by this system. We used the 4-km resolution data for the analyses to match the spatial scale

of empirical errors for LC 0 locations (=5 km). We defined migration routes as straight lines between Argos locations obtained. We examined the relationship between the latitudes of the daily Argos locations of a marked bird and the northward progression of melting snow (southern limit of snow covered area along the route) using a general linear model. The statistical analyses were done using R 3.2.2 (R Core Team 2015).

RESULTS

1) Changes in snow cover in continental Asia and Japan

During the week before the irruption (26 December 2007 to 1 January 2008), snow cover extended across most of north-eastern China and eastern Russia, but did not extend to western Japan or the Republic of Korea, except in mountainous regions (Fig. 1).

2) Description of migrations

Spring migration in 2008

Bird 76320 commenced its spring migration on 1 April, moving northwards through western Honshu and Hokkaido to reach northern Hokkaido. It remained in southern Wakkanai from 27 April to 6 May, then crossed the Sea of Japan over Rishiri Island. After reaching the Asian mainland, it moved northeast along the Amur River through Khabarovsk on 12 May. It continued to move inland ca. 90 km north-northwest from Komsomolsk-on-Amur (50°54′N, 137°20′E), then it moved ca. 80 km south-southeast. After that, it moved northeast to the lower
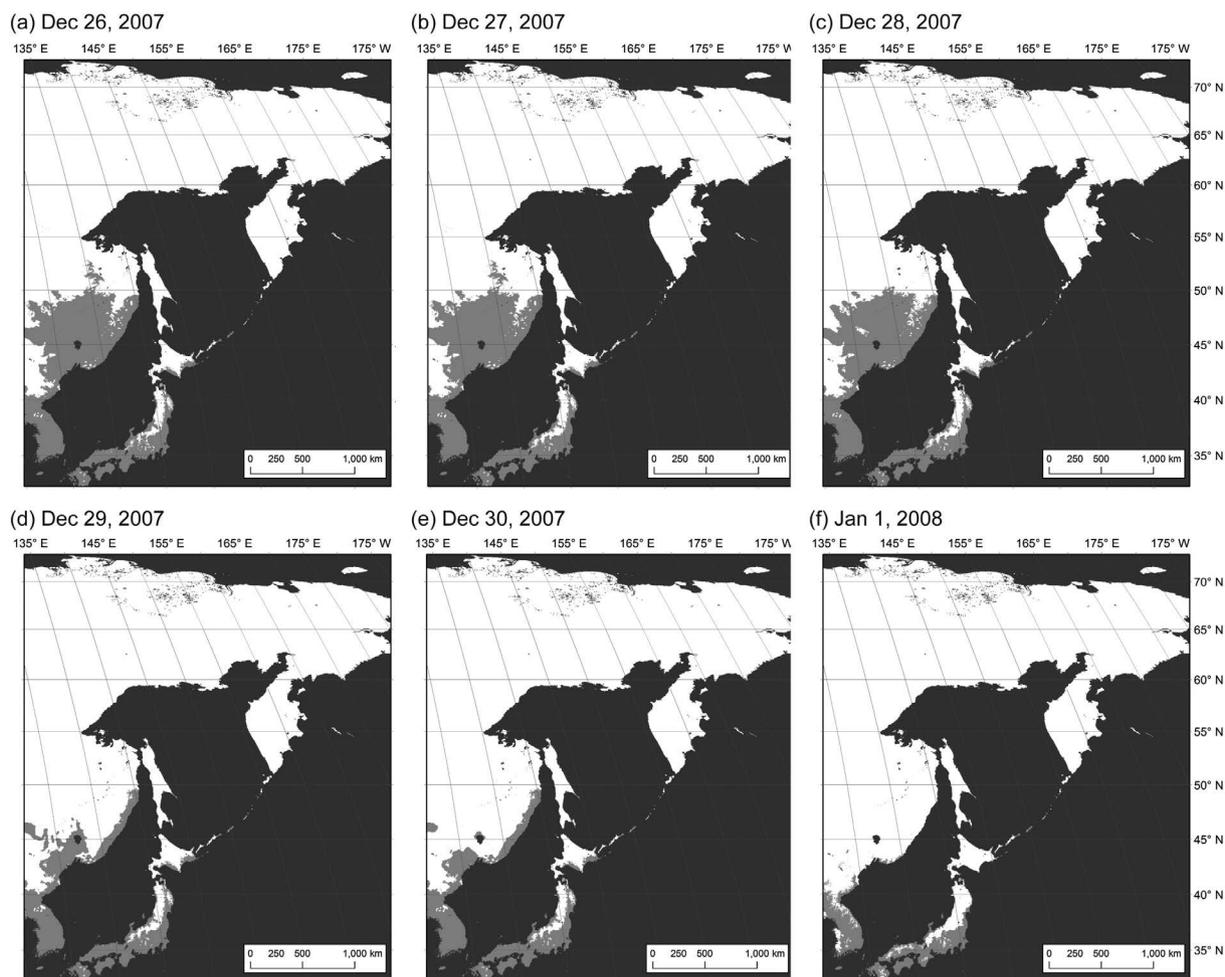
Fig. 1. Change in the distribution of snow cover (shown in white) in Eastern Asia from 26 December 2007 (a) to 1 January 2008 (f). Data for 31 December 2007 was not provided by the IMS daily Northern Hemisphere snow and ice analysis. Shortly after 1 January 2008, the irruptive movement of Rough-legged Buzzards into Japan occurred.

reaches of the Amur River. The bird was at the coast of Sakhalin Bay on 19 May and remained there until 6 June. It then moved south along the Amur River to Khabarovsk for two weeks, moved ca. 500 km inland to the border between China and Russia, and returned to Khabarovsk. Next, it moved to a location close to the border between China and Russia, ca. 120 km northeast from Hegang in Heilongjiang Province, China, and stayed there until 26 July. In the middle of August, ID 76320 moved to the coast of Sakhalin and remained there. The signal ceased at this location on 10 February 2009 (Fig. 2).

   Bird ID 78406 began its spring migration on 18 March, and bird ID 76322 set off on 14 or 15 April. They both migrated up western Honshu to northern Hokkaido. The signal from bird ID 76322 ceased on 5 May at Rebun Island. Bird ID 78406 remained at Wakkanai from 22 April to 3 May, it then moved across the Sea of Japan passing over Rishiri and Rebun islands on 5 May, before its signal was lost over the sea ca. 200 km northwest of Rebun

Island (Fig. 2).

   Bird ID 76326 moved to the eastern part of Gangwon Province, Republic of Korea, on 30 March, and stayed there until 4 April. It reached the plains region south of Lake Khanka on the Chinese–Russian border on 10 April, and stayed there for three days. The bird moved to an extensive cultivated area in northeastern Heilongjiang, northeastern China, and stayed there until 8 May. It left this stopover site then moved northeast, reaching Bolshoy Shantar Island in the Khabarovsk Krai, South-eastern Russia. After staying there until 21 May, the bird moved north and arrived at the western lowlands of the Chukotka Autonomous Okrug, North-eastern Russia, on 5 June (Fig. 2). The bird summered at $67°12'52''$N, $167°38'47''$E until 4 August, before moving to and remaining at $66°43'51''$N, $169°02'47''$E until 11 September (Fig. 2).

Autumn migration in 2008

   Bird ID 76326 left its summering area on 12 September and moved southwest along a route similar to the 2008 spring route. It reached an agricultural area north of the Lake Khanka on 16 October and stayed there until 30 January 2009. By 2 February, the bird reached an agricultural area of Hunchun City, far eastern Jilin Province, China (Fig. 3).

Spring migration in 2009

   Bird ID 76326 began its 2009 spring migration on 18 March and reached an agricultural area to the north of Lake Khanka. After staying there until 28 April, it moved northeast along a route similar to its 2008 spring route. The bird reached Chaunskaya Bay in the Chaunsky District of Chukotka, North-eastern Siberia, on 31 May, after staying in an area west of Lake Krasnoye, south-eastern Chukotka Autonomous Okrug, between 21 May and 26 May. It finally returned to its 2008 summering area on 3 June, and stayed there until 20 September (Fig. 3).

Autumn migration in 2009

   Bird ID 76326 began its autumn migration on 21 September 2009, using the same southeast route as in the previous autumn. It reached the agricultural area to the north of Lake Khanka and stayed there from 11 October to 22 December. By 24 December the bird reached northern Kangwon Province, Democratic People's Republic of Korea, on 22 January 2010 after staying near the border between North Hamgyong Province and Rason, Democratic People's Republic
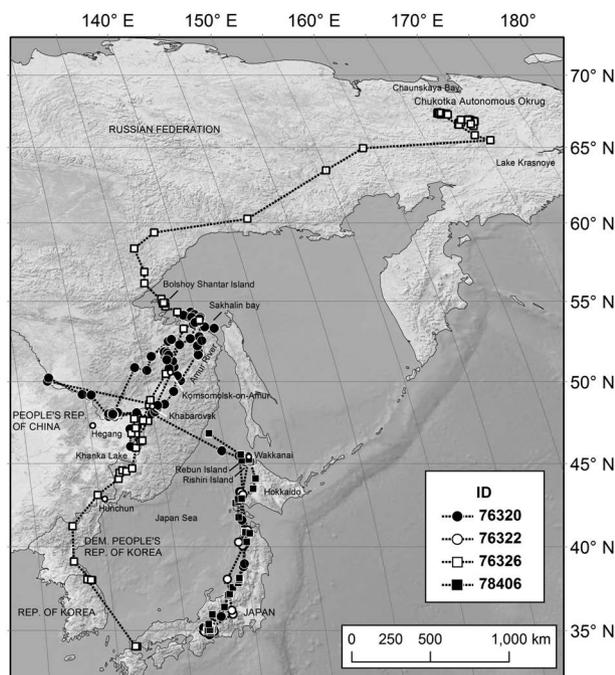
Fig. 2. The spring migration routes of four Rough-legged Buzzards satellite-tracked from Mie and Yamaguchi Prefectures, Japan in 2008. Circles and squares indicate the daily locations with the highest location quality. Dashed lines connect adjacent locations, they do not depict actual migration route. Filled circles and lines: bird ID 76320; open circles: bird ID 76322; open squares: bird ID 76326; filled squares: bird ID 78406.
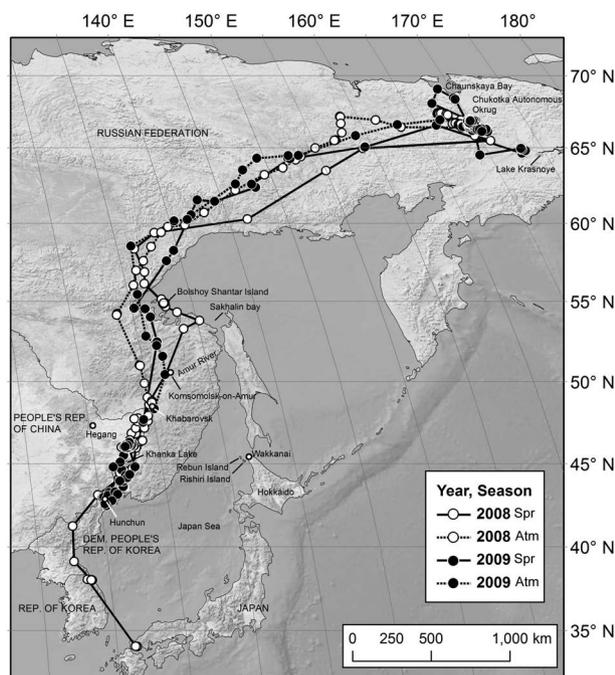
Fig. 3. Migration routes of Rough-legged Buzzard ID 76326 in 2008–2009. Circles indicate daily locations with the highest location quality. Solid and dashed lines connect adjacent locations; they do not depict actual migration routes. Open circles and solid lines show spring migration 2008; open circles and dashed lines show autumn migration 2008; filled circles and solid lines show spring migration 2009, and filled circles and dashed lines show autumn migration 2009.

of Korea, for four days. The bird stayed there until 22 February, and then arrived at ca. 260 km north on 27 February; signals from the PTT ceased on 9 March 2010 there (Fig. 3).

3) Relationship between spring migration and snow cover

In 2008, the northward spring migration of bird ID 76326 matched the northward movement of the southern snow cover limit (Table 1, Fig. 4, Fig 5). However, this relationship was relatively weak in spring 2009 (Table 1, Fig 6) because the bird moved northeast during 5–12 May before the snow had melted in the area (Fig. 6d). During mid- to late May the snow disappeared at the locations the bird reached (Fig. 6e).

DISCUSSION

This is the first study to attempt to show the spring and autumn migration routes of the Rough-legged

Table 1. Results of a general linear model with the latitude of Rough-legged Buzzard ID 76326 locations in spring 2008 as the response variable. The latitude of the southern limit of the snow covered area along the potential migration route of the bird (snow cover) and Julian date were set as the explanatory variables.

	Estimate	SD	P
2008			
Intercept	−2.35	1.57	0.14
Snow cover	0.49	0.06	<0.001
Julian date	0.21	0.02	<0.001
2009			
Intercept	4.75	3.92	0.23
Snow cover	0.25	0.13	0.07
Julian date	0.32	0.04	<0.001
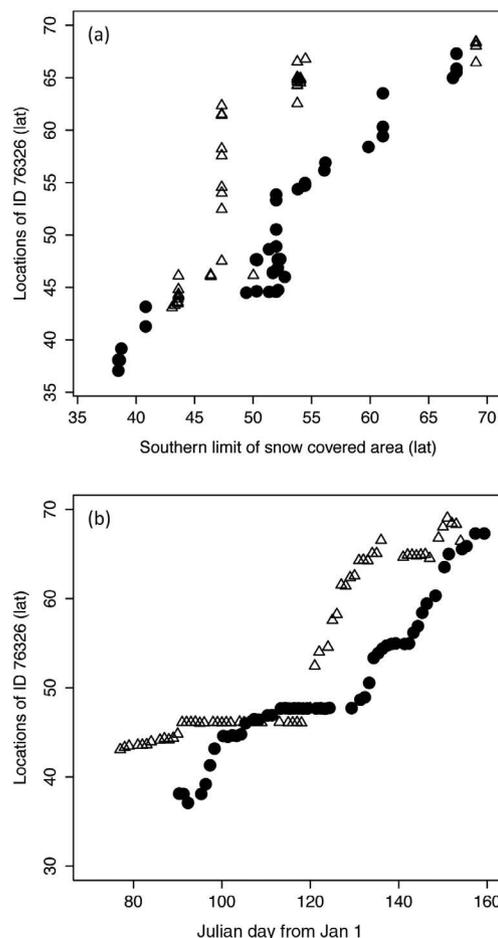
Fig. 4. The relationship between the southern limit of the snow covered area and locations of bird ID 76326 (a), and Julian date from 1 January and locations of bird ID 76326 (b). Closed circles indicate data for the 2008 spring migration and open triangles indicate data for the 2009 spring migration.
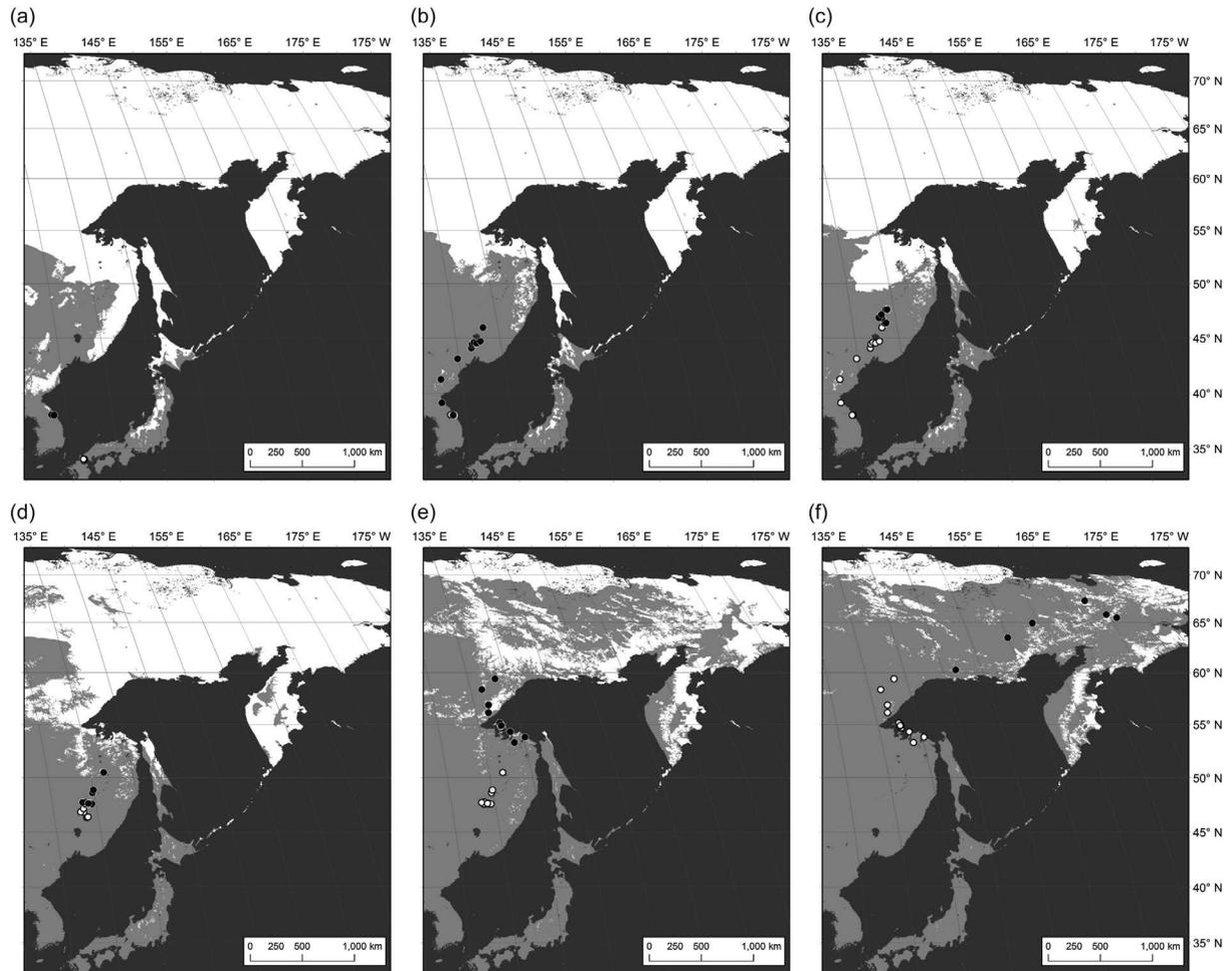
Fig. 5. The relationship between the distribution of snow cover (shown in white; 31 March (a), 14 April (b), 28 April (c), 12 May (d), 26 May (e), and 9 June (f)) and the movements of Rough-legged Buzzard (ID 76326) in spring 2008. Locations obtained during 10–31 March (a), 1–14 April (b), 15–28 April (c), 29 April–12 May (d), 13–26 May (e), and 27 May –9 June (f) are shown with filled circles. Previous locations are indicated with open circles for each panel.

Buzzard in Northeast Asia based on satellite tracking, although we were only able to track the complete migration of one individual. The summering site of bird ID 76326 was in the lowlands of the western part of the Chukotka Autonomous Okrug, Russia, and was used for two successive years. It seems likely that the bird occupied a breeding territory there. In 2009, it wintered north of Lake Khanka, in an area near the Chinese-Russian border, and in an agricultural area in Hunchun, eastern Jilin Province, China. This area is within the regular wintering range of the species (Cramp & Simmons 1980).

The migration routes within Japan of one individual tracked from Yamaguchi Prefecture (ID 76326) and three other individuals tracked from Mie Prefecture were clearly different. All birds moved northwards at

the beginning of their migrations, but bird ID 76326 used a route crossing the Tsushima Strait to reach the Korean Peninsula, whereas the other birds used a route that took the up Honshu to western Hokkaido. After reaching continental Asia, bird ID 76320 lacked a clear the migration direction, and it moved widely within the Amur River basin. This erratic movement may reflect the inexperienced behaviour of a juvenile bird (Hake et al. 2001, 2003). In this species, birds typically breed for the first time at 2–3 years of age (Cramp & Simmons 1980).

We confirmed that most of Northeast Asia was covered with snow at the end of 2007, except for the Republic of Korea and western Japan. Before the winter irruption into western Japan at the beginning of 2008, a strong cold wave hit Northeast
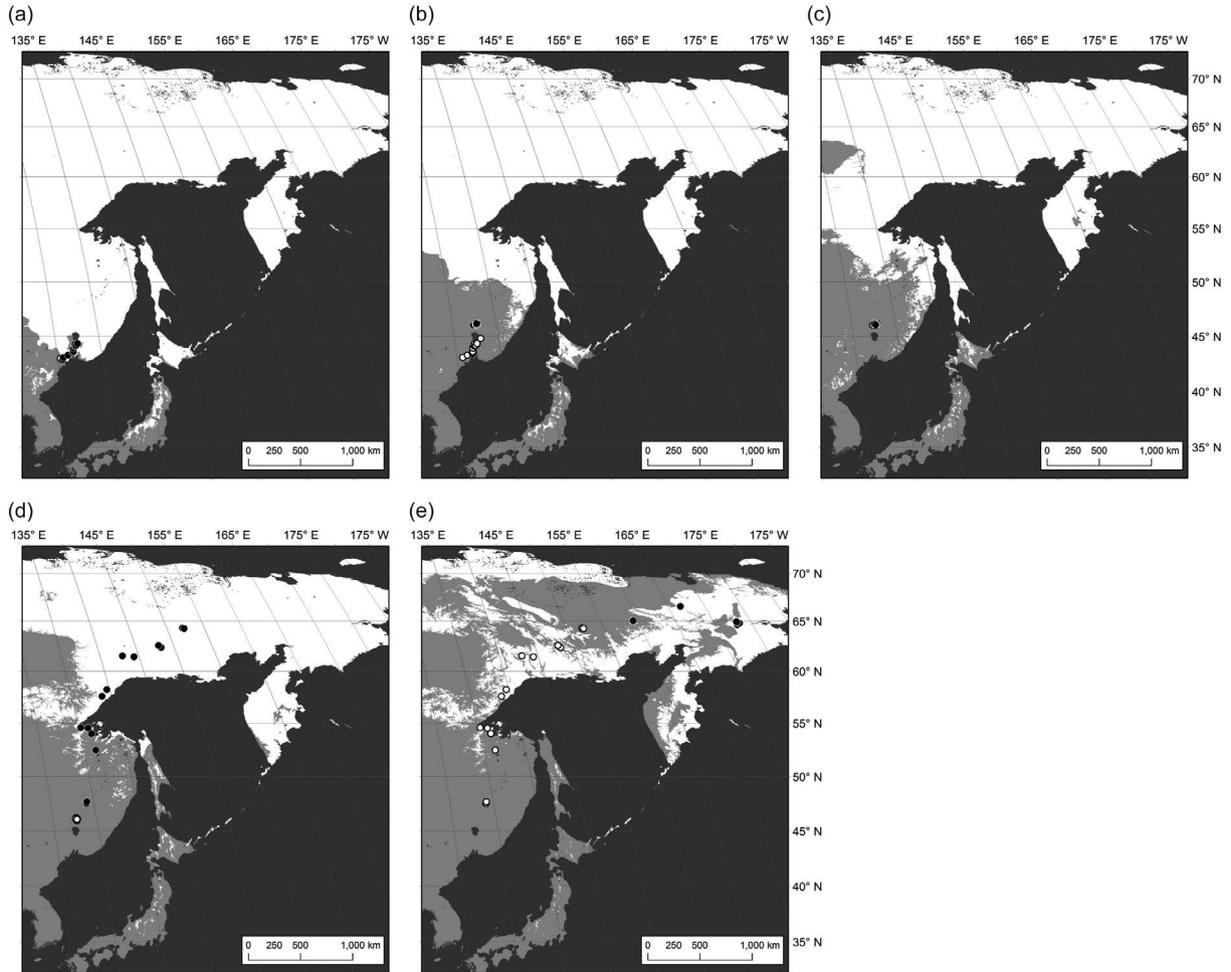
Fig. 6. The relationship between the distribution of snow cover (shown in white; 31 March (a), 14 April (b), 28 April (c), 12 May (d), and 26 May (e)) and the movements of Rough-legged Buzzard (ID 76326) in spring 2009. Locations obtained during 18–31 March (a), 1–14 April (b), 15–28 April (c), 29 April–12 May (d), and 13–26 May (e) are indicated with filled circles. Previous locations are indicated with open circles for each panel.

Asia, which may have induced winter movements in Rough-legged Buzzards wintering in northeastern China and Far East Russia (Kuno 2013). This pattern is similar to previous observations in Germany and Switzerland (Dobler et al. 1991; Knaus 2012), and suggests that the irruption was caused by low temperature and snow cover (Dobler et al. 1991; Knaus 2012).

During spring migration, there was generally a positive relationship between the northward movements of bird ID 76326 and the northward progression of snow melt along the migration route, considering the Julian date as a covariate. In many migratory birds, the timing of departure for the summering grounds and the migration patterns are controlled by the photoperiod and endogenous clocks. For many long-dis-

tance migratory birds, food is important not only for pre-migratory fattening, but also during the migration at stopover sites (Alerstam 1990; Gill 2007; Carey 2009). Rough-legged Buzzards prey mainly on voles and lemmings in open habitats (Pasanen & Sulkava 1971; Cramp & Simmons 1980; Potapov 1988). Sonerud (1986) reported that Rough-legged Buzzards increasingly used a clear-cut area in a forest as the snow cover disappeared. During winter, rodents have a subnivean existence, thus the trails of small mammals were less visible in the clear-cut area (Sonerud 1986). Therefore, snow cover would have a negative effect on the foraging efficiency of avian predators hunting small mammals in open habitats. Rough-legged Buzzards use the UV-reflecting scent marks of voles to assess hunting areas (Koivula &

Viitala 1999) and they seem to lack the ability to localize prey by sound (Rice 1982). These findings are consistent with direct observations that show Rough-legged Buzzards do not attempt to catch voles beneath the snow (Baker & Brooks 1981; Toshiro Yoshioka personal communication) and further support the supposition that the northward movement of bird ID 76326 was influenced by the timing of snow melt.

In both the 2008 and 2009 spring seasons, the northward progression of snow melt preceded the migration of bird ID 76326, except in early May 2009. During spring migration, arctic breeding such as Canada Goose *Branta Canadensis,* Greater Snow Goose *Anser caerulescens* and Pink-footed Goose *A. brachyrhynchus* often follow the northward progression of snow melt and use stopover areas shortly after open water and bare ground first become available (Wege & Raveling 1983; Hupp et al. 2001) because newly emerging plants often have high nutritional values (Fox et al. 1991; Hupp et al. 2001). Greater Snow Goose *A. caerulescens* most likely select areas with 10–49% snow cover and select against snow-free areas (Hupp et al. 2001). For snow geese, habitat quality improves when larger areas of bare ground provide more foraging opportunities, and exposed inland plant communities are more abundant. For Rough-legged Buzzards, habitat quality is likely to improve a bare ground is completely exposed because locating prey becomes easier as they lose their hiding places beneath the snow. When snow cover temporarily extended southward due to an early spring cold air system, it would have been favourable for bird ID 76326 to move north well after the northward progression of snowmelt.

ACKNOWLEDGMENTS

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