Using a Remote Technology in Conservation: Satellite Tracking White-Naped Cranes in Russia and Asia

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Abstract: *We investigated the application of satellite tracking to the conservation of cranes and other waterbirds and the necessity of international cooperation in the conservation of migratory species. Using satellite tracking, we followed 11 White-naped Cranes (*Grus vipio*) on migration from their breeding grounds in eastern Russia to their wintering grounds in China and Japan. From 1991 to 1993, we captured cranes with the aid of helicopters and attached satellite transmitters (platform transmitter terminals) to captured birds via a harness system. We tracked cranes for 156 days on average, across 2558 km, and obtained an average of 339 locations per crane. Cranes migrated over 8–90 days. During migration, birds spent 1–30 days at 4–12 rest sites. Cranes wintered at two main sites: Poyang Lake, China, and Izumi, Japan. All seven cranes migrating to the Poyang Lake area rested at the Yellow River delta–Bohai Bay, China, and all three traveling to Izumi rested in the Demilitarized Zone on the Korean Peninsula. Other important rest sites were marshes around the Wulagai River, Huainan, Hu-Lun Lake, Linyi, Tangshan, the Three Rivers (Sanjiang) Plain, Tianjin, and the Xar Moron River, all in China, and Lake Khanka–Xinghai at the border of China and Russia. The habitats resting cranes used most frequently were plains, including upland areas, marshes, and rivers. Although nature reserves exist at the two main wintering sites of Poyang Lake and Izumi, rest sites used by cranes were poorly protected. Even when areas used by cranes for resting or wintering were included in nature reserves, reserves were threatened by human encroachment and development. To ensure that cranes can continue to migrate successfully, it is crucial that the establishment of reserves continues at important rest areas and that the areas covered by reserves at wintering sites be extended to include more of the areas utilized by cranes. Also, development and human disturbance should be minimized in reserve areas. Because long-distance migrant birds, including cranes, range over such large areas, conservation of these organisms and their habitats necessitates multinational communication and cooperation.*

Key words: Asia, conservation, *Grus vipio*, Russia, satellite tracking, White-naped Crane

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Utilización de una Tecnología Remota en Conservación: Rastreo por Satélite de Grullas de Nuca Blanca en Rusia y China

Resumen: *Investigamos la aplicación del rastreo por satélite a la conservación de grullas y otras aves acuáticas y la necesidad de cooperación internacional en la conservación de especies migratorias. Utilizando el rastreo por satélite, seguimos la migración de 11 grullas de nuca blanca (*Grus vipio*), desde sus áreas de reproducción en Rusia oriental hasta su área de hibernación en China y Japón. De 1991 a 1993 capturamos grullas con la ayuda de helicópteros y les colocamos transmisores de satélite (terminales de transmisor de plataforma) mediante un sistema de arnés. Rastreamos a las grullas por 156 días en promedio, a lo largo de 2558 km, y obtuvimos un promedio de 339 localidades por grulla. Las grullas migraron por 8-90 días. Durante la migración, las aves estuvieron de 1-30 días en 4-12 sitios de descanso. Las grullas invernaron en dos sitios principales: Lago Poyang, China e Izumi, Japón. Las siete grullas que migraron al área del Lago Payong descansaron en el delta del Río Amarillo/Bahía Bohai, China, y las tres que viajaron a Izumi descansaron en la Zona Desmilitarizada en la Península Coreana. Otros sitios de descanso importantes fueron humedales alrededor del río Wulagi, Huainan, Lago Hu-Lun, Linyi, Tangshan, la Llanura Tres Ríos (Sanjiang), Tianjin y el Río Xar Moon, todos en China, y el Lago Khanka/Xinghai en la frontera entre China y Rusia. Los hábitats utilizados más frecuentemente para descanso fueron llanuras, incluyendo áreas elevadas, ciénegas y ríos. Aunque existen reservas naturales en el Lago Poyang e Izumi, los dos principales sitios de hibernación, los sitios utilizados para descanso están mal protegidos. Aun cuando las áreas utilizadas por las grullas para descanso estuvieran en reservas naturales, las reservas estaban amenazadas por invasión y desarrollo humano. Para asegurar que las grullas puedan continuar migrando exitosamente, es crucial que continúe el establecimiento de reservas en áreas de descanso importantes y que se extiendan las áreas cubiertas por reservas en sitios de hibernación para incluir más de las áreas utilizadas por grullas. También, se debe minimizar el desarrollo y la perturbación humana en las áreas de reserva. Debido a que las aves migratorias de larga distancia, incluyendo grullas, se distribuyen en áreas muy extensas, la conservación de estos organismos y sus hábitats requiere de comunicación y cooperación multinacionales.*

Palabras Clave: Asia, conservación, Grulla de Nuca Blanca, *Grus vipio*, rastreo por satélite, Rusia

Introduction

Animals that migrate over long distances represent special challenges for conservation. Following moving animals and identifying important habitats over large spatial scales are technically difficult. Further, studying species that migrate across international boundaries can be difficult for political reasons and necessitates communication and cooperation between nations that may have unstable and sensitive internal and external political situations. Over the last 20 years, satellite-based technologies have been used increasingly to determine animal locations over medium to large scales and to assess habitat characteristics at those scales (e.g., Fancy et al. 1988; Priede & Swift 1992). The main advantages of these techniques are the large spatial scales over which they can be employed and the fact that data can be collected from remote locations. Consequently, satellite technologies are now standard tools in wildlife research.

Satellite tracking has been used extensively in recent years to follow a variety of animals in both marine and terrestrial environments (e.g., hawksbill turtles [*Eretmochelys imbricata*], Horrocks et al. 2001; minke whales [*Balaenoptera acutorostrata*], Heide-Jorgensen et al. 2001; South American sea lions [*Otaria flavescens*], Campagna et al. 2001; Wandering Albatrosses [*Diomedea exulans*], Shaffer et al. 2001; White Storks [*Ciconia ciconia*], Berthold et al. 2001; and caribou [*Rangifer tarandus caribou*], Schaefer et al. 2000). Satellite tracking is a particularly appropriate technique for migration studies because of the efficacy of tracking devices over large areas, the relative precision of the resulting locations, and the hands-off nature of data collection after transmitters are attached to animals. By allowing researchers to investigate migration patterns, including start and end points, migration routes, locations of important stopover areas, and habitat types used by migrating animals, satellite tracking can provide much information critical to conservation. For example, the importance of the western Sudan and Chad for White Storks (*Ciconia ciconia*) was unknown until birds were satellite-tracked and was not apparent from banding studies (Berthold et al. 2001). Two nature reserves have been established in North Korea because of data gleaned from satellite-tracked cranes (Chong et al. 1992, 1994; Chong & Morishita 1996).

The crane family (Gruidae) is one of the most endangered families of birds worldwide. The family includes 15 species, of which 10 are considered threatened with extinction (World Conservation Union 2000), and an additional species is recommended for threatened status (Archibald & Meine 1996). Most species of cranes are migratory, and migrations range in length from 400 to 4000 km (Harris 1994). Consequently, migrations frequently occur across international borders and through politically sensitive areas. Recently, satellite tracking has been used to identify the locations of cranes and follow their migratory movements. Studies of cranes in which satellite tracking has been used have involved Common (*Grus grus*), Demoiselle (*Anthropoides virgo*), Hooded (*Grus monacha*), Red-crowned (*Grus japonensis*), Siberian (*Grus leucogeranus*), and White-naped (*Grus vipio*) cranes (Higuchi et al. 1992, 1994*a*, 1994*b*, 1996, 1998; Kanai et al. 2000, 2002; Harris et al. 2000; Higuchi & Minton 2000).

Previous studies involving satellite tracking of White-naped Cranes have largely focused on migration routes from the species' wintering site in Izumi, Japan (Higuchi et al. 1996). In a preliminary report, we described the migration pathways of four White-naped Cranes we satellite-tracked from eastern Russia (Higuchi et al. 1994*a*). Here, we examine the movements of an additional seven White-naped Cranes that were successfully tracked from their breeding sites in eastern Russia to wintering sites in China and Japan. We investigated migration patterns, including routes, stopover sites, distances traveled, and general habitat characteristics of sites used by cranes. We also describe issues relevant to the conservation of cranes, based on our identification of important crane sites with satellite tracking. Finally, we discuss the application of satellite tracking to the conservation of birds and other animal species.

Methods

The White-naped Crane is categorized as vulnerable in BirdLife International's Red Data Book (BirdLife International 2001). White-naped Cranes breed in southeastern Russia, northeastern Mongolia, and northeastern China and winter in the Yangtze River Basin in China, along the Korean Peninsula, and in southern Japan (BirdLife International 2001). The species frequents wetlands, grasslands, and agricultural lands and has an omnivorous diet that includes wetland plant parts, cereals, insects, and small vertebrates (Archibald & Meine 1996).

With the assistance of helicopters, we captured eight White-naped Cranes at Daursky Nature Reserve (50°N, 115°E), two at Khingansky Nature Reserve (49°N, 129°E), and one at Muraviovka Wildlife Refuge (49°55′N, 127°39′E) in eastern Russia in July 1991–1993 (Table 1). Daursky Nature Reserve is approximately 45,700 ha in size, and its land base includes lakes, marshlands, grasslands, and forests. Khingansky is 97,300 ha in size; about one-third of this area is marshlands and the remaining area is forest. Muraviovka Wildlife Refuge covers 34,000 ha and includes forests, marshlands, rivers, lakes, and ploughed fields.

Following capture, we attached satellite transmitters (platform transmitter terminals, PTTs) to cranes and released them immediately, except for crane 9377 in 1991; this bird was held in captivity near Daursky Nature Reserve until its release in early September 1991. In 1991 we used model T-2038 PTTs of the Nippon Telegraph and Telephone Corporation (NTT). The PTTs weighed 80 g each and measured 80 × 60 × 35 mm, excluding the 180-mm antenna. They were attached to cranes with a harness system. Harnesses consisted of ribbons treated with Teflon, one of which was attached to each of the four corners of the PTT. Ribbons met at the crane's breastbone, where they passed through a small tube and were sewn together with cotton thread. Thus, the PTT fell off when the thread was worn through. The harness and PTT together weighed about 130 g, which is approximately 2% of the body weight of an adult White-naped Crane (Higuchi et al. 1996).

Table 1. Summary of satellite-tracking information for 11 White-naped Cranes tracked from their breeding to wintering grounds.[a]

Year tracking began and crane identification no.	*Age*	*Sex*	*Capture site*	*Tracking period*	*Tracking distance (km)*	*Days for migration*	*Battery lifespan (days)*	*No. of locations[b]*
1991								
9377	A	M	Daursky	7 September–25 December	2348	26	109	108
1992								
9374	A	M	Daursky	15 July–28 October	2697	8	106	216
9375	A	M	Daursky	13 July–19 December	2897	13	160	370
9377	U	U	Khingansky	8 July–9 January 1993	2790	68	186	182
1993								
20247	A	F	Daursky	8 July –24 December	2205	53	170	439
20248	A	U	Daursky	12 July–17 December	2580	21	159	421
20250	A	U	Daursky	8 July–19 December	2649	33	165	441
20252	A	U	Daursky	13 July–3 January 1994	2457	64	175	414
20253	A	M	Daursky	15 July–13 December	2670	37	152	357
20271	A	U	Muraviovka	10 July–20 December	2466	55	164	403
20273	A	F?	Khingansky	11 July–31 December	2375	37	174	376

[a] *Data on four cranes presented in Higuchi et al. (1994a). Abbreviations: A, adult; F, female; M, male; U, unknown.*
[b] *Number of locations includes location classes 0, 1, 2, and 3.*

In 1992 and 1993 we used NTT model T-2050 PTTs. In 1992 these weighed 45–55 g without the harnesses attached and measured 56 × 33 × 18 mm. In 1993 transmitters were slightly larger, weighing 80 g without the harness and measuring 60 × 40 × 30 mm. In both 1992 and 1993, transmitter antennas were 180 mm long. As in 1991, we used Teflon ribbon to attach PTTs to cranes. Transmitter activity was set to 6 hours active and 12 hours inactive with 60 seconds between pulses for both models of PTT and in all years of the study.

Satellite location data ranged in accuracy from class 0 (least accurate) to class 3 (most accurate). We assumed that the location data of class 1 and above were accurate to within 1 km, in line with maximum margins of error given by Keating et al. (1991) and Service Argos (1994). We included location data of class 0 when determining migration routes as long as locations obtained were reasonable with respect to tracking times and location data for classes 1–3. We received some aberrant locations that were not in line with tracking times and other location data, and we excluded these from analyses.

We used published materials (Scott (1989) and maps from the U.S. National Imagery and Mapping Agency (U.S. Defense Mapping Agency 1988*a*, 1988*b*, 1994*a*, 1994*b*) to identify general characteristics of habitats used by migrating cranes. We determined whether or not satellite locations were in reserve areas based on publications and personal communications (Scott 1989; Ma & Li 1994; Chong & Morishita 1996; Harris et al. 2000; S. Chan, personal communication; Z. Ma, personal communication).

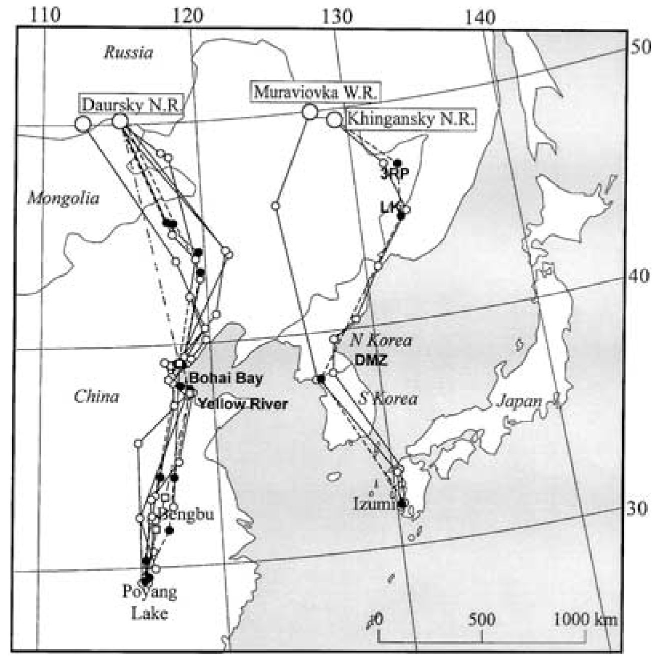

*Figure 1. Migration routes of White-naped Cranes (*Grus vipio*) from their breeding grounds in Russia to their wintering grounds in China and Japan (3RP, Three Rivers Plain; LK, Lake Khanka; DMZ, demilitarized zone). Large open circles mark capture sites, squares with dashed and dotted lines show the single bird tracked in 1991, filled circles and dashed lines show birds tracked in 1992, and small open circles with solid lines show routes used in 1993. Data on migration pathways of four birds was previously reported by Higuchi et al. (1994a).*

Results

We tracked 11 White-naped Cranes from July through January each year from 1991 through 1994 and obtained 108–441 (mean = 338.82, SE = 33.11) satellite locations per individual. On average, 33.7% (SE = 4.4) of these were in location class 0, 52.7% (SE = 3.4) were in location class 1, 8.1% (SE = 1.2) were in location class 2, and 5.5% (SE = 1.4) were in location class 3. We tracked cranes for an average of 2557.64 km (SE = 59.88, range = 2205-2897). Battery lifespans ranged from 106 to 186 days (mean = 159.36, SE = 7.46; Table 1). During this time, cranes spent 8–64 days in migration (mean = 37.73, SE = 5.83; Table 1). After leaving their individual breeding sites but before departing on migration, two cranes spent 26–53 days at staging sites within the breeding area.

Cranes occupied two main wintering areas, Poyang Lake in China and Izumi in Japan. These locations were the winter homes of five and three cranes, respectively. In addition, two cranes wintered <100 km to the north of Poyang Lake at Dagian Lake and Tai Lake. The remaining crane wintered west of Bengbu, also in China (Fig. 1; Appendix 1). Locations occupied by wintering cranes were at lakes, plains (upland and lowland areas), and rivers. After departing the breeding area, the approximate number of days our individual White-naped Crane spent at resting sites en route varied from 1 to 30 (mean = 5.39, SE = 1.24; Appendix 1). Cranes flew 258 km on average between rest stops detected by satellite tracking (SE = 22.1; Fig. 2).

There was some variation in the routes and stopover sites used by individual cranes on migration (Fig. 1). However, all cranes migrating to the Poyang Lake region rested around the mouth of the Yellow River–Bohai Bay (Fig. 3a, Appendix 1). Other areas where more than one migrating crane stopped en route to Poyang, included marshes around the Wulagai River (2 cranes), Huainan (2), Hu-Lun Lake (2), Linyi (2), Tangshan (6), Tianjin (2), and the Xar Moron River (2) (Appendix 1). Cranes spending the winter at Izumi also used some common rest sites en route. Two of the three Izumi birds rested on the Three Rivers (Sanjiang) plain and at Lake Khanka–Xinghai, and all rested in the Demilitarized Zone (DMZ) on the Korean Peninsula. Two birds were also located in Fukuoka Prefecture before arriving at Izumi (Fig. 1; Appendix 1). Plains,

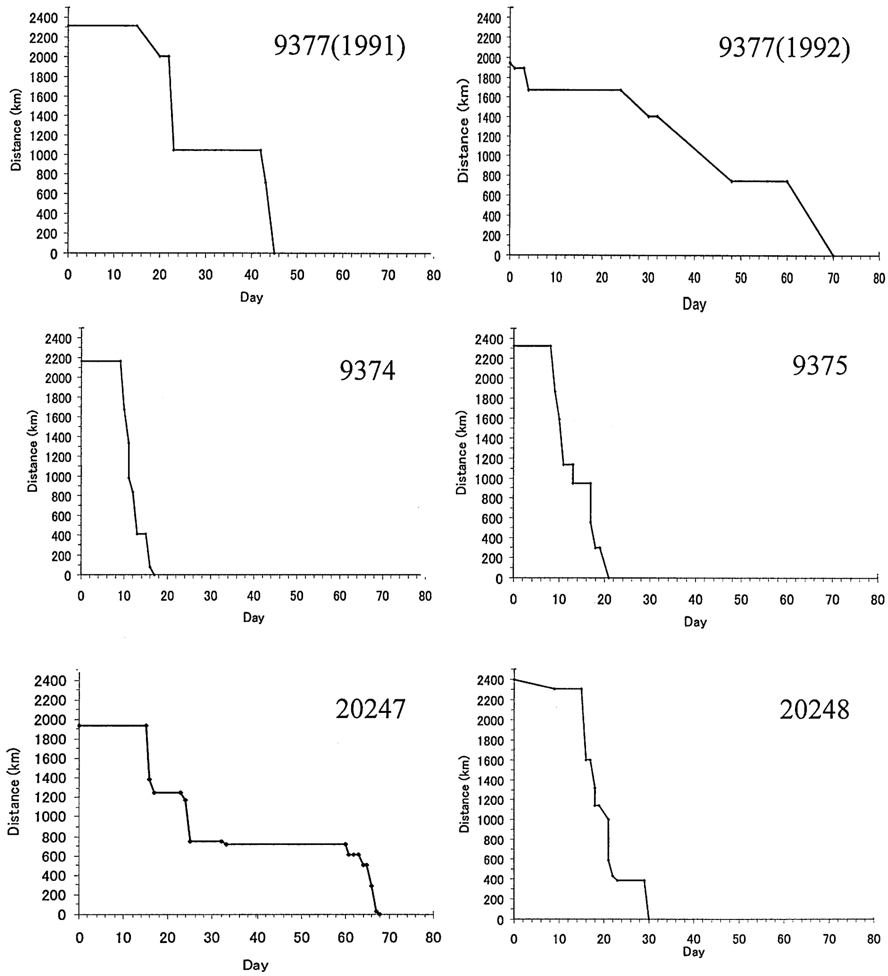

*Figure 2. Migration patterns of White-naped Cranes (*Grus vipio*): distance from wintering site vs. time. Crane identification numbers are in the top right of each panel. Data on migration patterns of four birds was previously reported by Higuchi et al. (1994a).*

followed by marshes and rivers, were the most frequently identified locations used for resting by migrating cranes (Appendix 1).

Individual cranes were recorded resting at 4–12 sites (mean = 7.5, SE = 0.79) before arriving at their wintering grounds (Appendix 1). Of rest sites used by cranes, however, only an average minimum of 14% and average maximum of 23% (SE = 3.3 and 3.6, respectively) occurred in nature reserves. At the Yellow River delta–Bohai Bay, reserves have been established, but cranes often use areas beyond reserve boundaries (Fig. 3a; Z. Ma, personal communication). For example, when we used a geographic information system to delineate 10-km buffer zones around reserves and examined satellite locations within buffers and reserved areas from 1991 to 1993, 66.2% of crane locations were inside reserves. When we digitally created 20-km buffers around reserves, only 61.3% of locations fell within protected areas. Similarly, although reserves exist at both main wintering sites, Poyang Lake and Izumi, not all areas used by cranes at Poyang Lake are protected (Fig. 3b; Z. Ma, personal communication). When we digitally established 10-km buffer zones around reserves at Poyang Lake and considered locations within buffers and reserved areas from 1991 to 1993, 71.5% of crane locations were inside reserves. For 20-km buffer zones, this value was 66.8%. Also, habitats used by the three cranes recorded wintering outside Poyang and Izumi are not protected.

Discussion

Rest Areas and Their Conservation

Migration patterns differed among individual White-naped Cranes when birds moved from breeding to wintering areas, but they did share some common rest sites. Rest areas used by more than one migrating crane that were also reported to be used by White-naped Cranes in previous studies were parts of Bohai Bay (China), Cholwon (Korean Demilitarized Zone), Lake Khanka–Xinghai (Russia-China), northwestern Odaejin (North Korea), Panmunchom (Korean Demilitarized Zone), Sonbon (Russia–China–North Korea), the Yellow River delta (China), and locations within the Three Rivers (Sanjiang) Plain (China) (Higuchi et al. 1992, 1996; Chong et al. 1994; Harris et al. 2000). Red-crowned and Siberian cranes also use some of these sites for breeding, wintering, or migration (e.g., Bohai Bay and the Yellow River

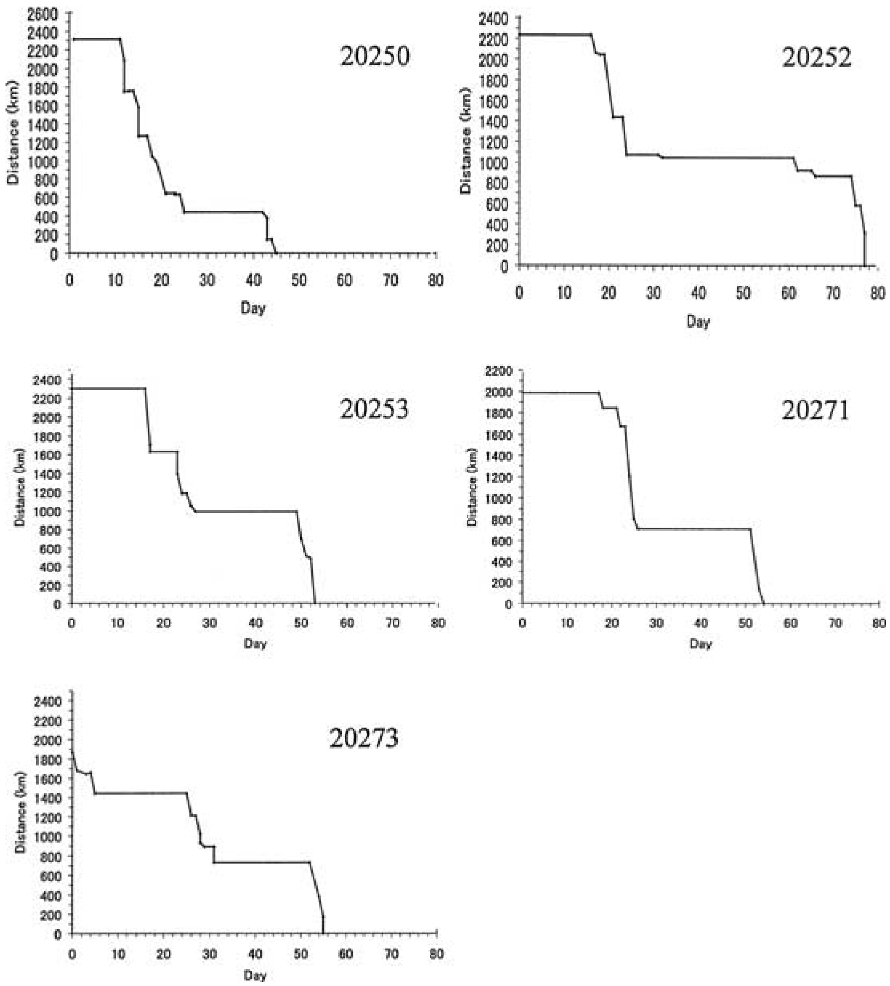

Figure 2. (continued)

delta, Cholwon, Lake Khanka–Xinghai, Odaejin) (Pae & Won 1994; Higuchi et al. 1998; Kanai et al. 2002).

The use of some resting sites located in our study by more than one species of cranes emphasizes the importance of conserving these sites. Rest sites used by migrating cranes in our study are poorly protected, although investigators have called for the establishment of an international network of reserves along crane migration flyways (Ichida 1994), and much recent progress has been made toward this goal (Harris et al. 2000). On average, less than one-third of all rest sites used by cranes were included in nature reserves. In addition, although nature reserves have been officially designated in some areas, this designation may afford little real protection for cranes and their habitats, with pressure on both continuing. For example, in Chinese nature reserves and peripheral areas used by cranes in our study, disturbances include damming, fishing, hunting, the collection of birds' eggs, mining, reed-cutting, and grazing (Scott 1989). Outside reserved areas, disturbances also include drainage of wetlands, conversion of wetlands into agricultural lands, factory construction, removal of water from wetland and lake systems, and salt extraction (Scott 1989; Chong et al. 1994; Kanai et al. 1994; Meine & Archibald 1996). Beyond disturbances related to specific developments, many areas in China used by cranes in our study, including areas inside nature reserves, are subjected to "excessive human disturbance" (Scott 1989). Such disturbance is often detrimental to cranes, most species of which are considered disturbance-sensitive (Archibald & Meine 1996).

Even where cranes themselves are protected, the habitats they depend on may not be. For example at some locations in the Korean DMZ, cranes have been designated "natural monuments" (Scott 1989; Chong & Morishita 1996), but no protection exists for the cranes' habitats. Currently, civilian activity is prohibited in the DMZ, and activities within the neighboring Civilian Control Zones (CCZ) are closely monitored. Therefore, the habitats used by cranes are undisturbed or subjected to limited and tightly controlled disturbances. However, development and changing agricultural practices in areas adjacent to the CCZ will threaten cranes' use of wintering sites if these human activities extend into the CCZ itself (Higuchi & Minton 2000). Also, any future development in the DMZ proper would pose a serious threat to the integrity of important crane habitats (Higuchi et al. 1996).

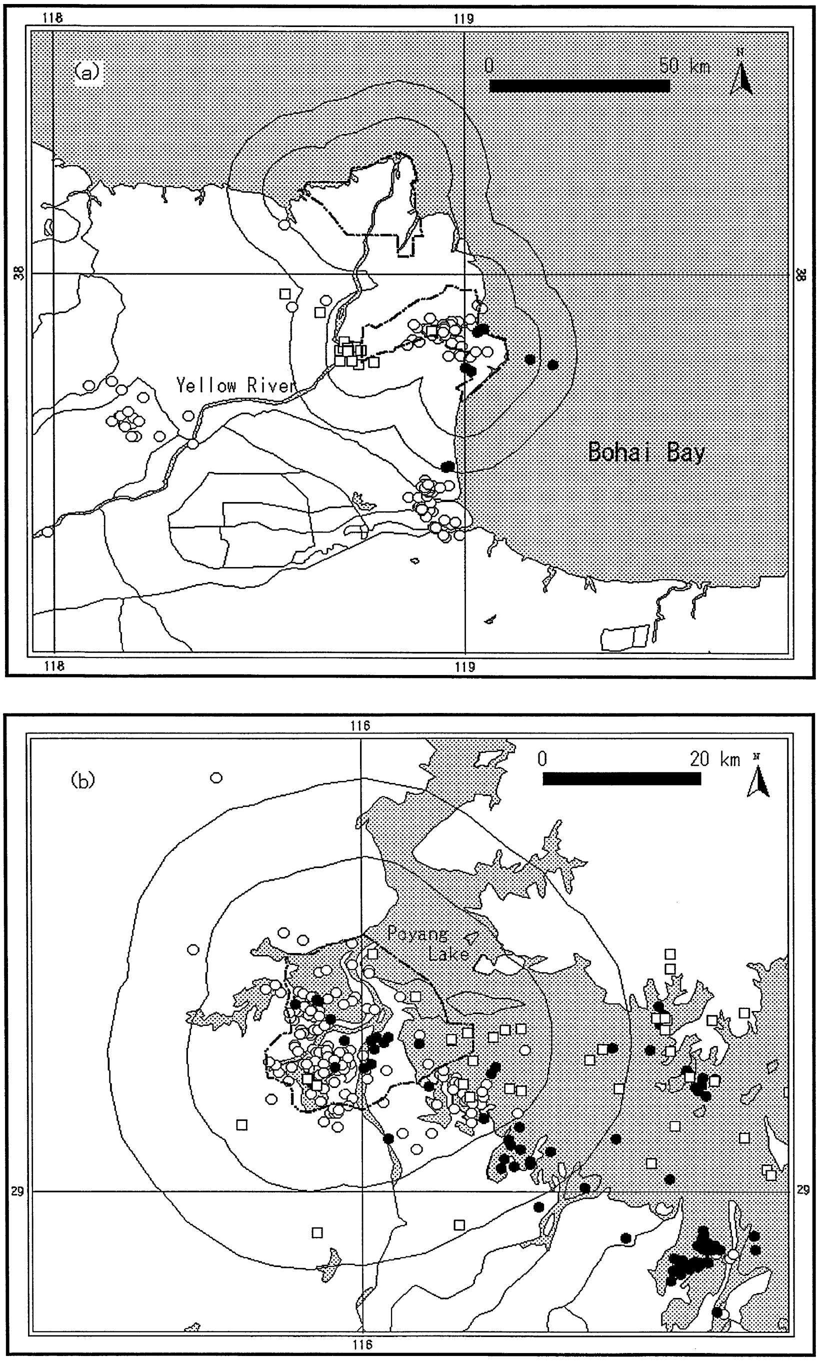

*Figure 3. Locations of White-naped Cranes (*Grus vipio*) and nature reserves at two critically important rest areas: (a) southern Bohai Bay and the mouth of the Yellow River and (b) Poyang Lake. Heavy dashed lines indicate the approximate boundaries of nature reserves, which are surrounded by buffers at distances of 10 and 20 km (see text). Points represent crane locations: open squares, 1991; filled circles, 1992; open circles, 1993. Water bodies are shaded. Some location data was previously reported by Higuchi et al. (1994a).*

In cases where both cranes and their habitats are protected, the amount of protected land may not be sufficient to ensure the survival of cranes (e.g., at Lake Khanka-Xinghai, Russia, and Kumya, North Korea). At Lake Khanka-Xinghai, the Russian and Chinese governments have established reserves and have designated these areas an international sanctuary (Harris et al. 2000). Current reserves, however, are inadequate to protect cranes using the lake because cranes often occur outside reserve areas. Also, reserves are composed of core zones adjacent to buffer zones, and buffer zones are not protected from encroaching development (Shibaev & Surmach 1994). At Kumya there is a sanctuary for wintering birds (Protected Area 275; Chong et al. 1994), but our study demonstrated that cranes also use marsh areas north of Kumya (around Sondok) that are currently unprotected. Therefore, extending the boundaries of both the Lake Khanka-Xinghai and Kumya reserves to include other areas used by cranes is necessary to safeguard the birds in these areas.

Wintering Sites and Their Conservation

Compared with rest sites on the migration route, cranes were better protected on their wintering grounds because reserves exist at both Poyang Lake, China, and Izumi, Japan. At Poyang Lake, however, cranes ranged beyond the reserve boundaries, suggesting that existing protected areas are insufficient to ensure the long-term survival of cranes using the lake. This is also the case for the endangered Siberian Cranes and Oriental White Storks (*Ciconia boyciana*), which winter there (Harris et al. 1995; Kanai et al. 2002; H.H., unpublished data). Further, human settlement is extensive at Poyang, with coincident land uses including fishing, buffalo grazing, vegetation harvesting, and agriculture (Scott 1989). Some hunting also occurs inside the reserve, although it is officially prohibited, and poisoning threatens cranes and other waterfowl (Ma & Li 1994). In unreserved areas of the lake, developments and disturbances include pollution, wetland drainage and conversion to agricultural lands, hunting, fishing, and removal of water for irrigation (Scott 1989). Although very low-level human use is probably only minimally disturbing to cranes, levels of use at Poyang are expected to disturb the birds.

Upstream of Poyang Lake itself, the Three Gorges Dam on the Chang–Yangtze River is a serious threat to cranes and other aquatic birds (e.g., the endangered Swan Goose [*Anser cygnoides*]) that use Poyang. Construction of this dam began in 1994 and is projected to end in 2009. Downstream of the dam, changes in hydrologic regimes are expected to affect birds. Although water will flow through the dam in flood periods, at Poyang the dam will cause artificially low water levels in summer and high levels in winter (Meine & Archibald 1996; Archibald & Mirande 1999). This is predicted to disrupt the food bases of aquatic birds and may also affect their distribution, forcing birds to use unprotected areas and move closer to humans. As well as increasing the likelihood of direct disturbance, living in closer proximity to humans may increase the consumption of poison bait by birds (L. Yunzhen et al. 1996, cited in BirdLife International 2001).

At Izumi, birds in reserve areas may be overcrowded (Scott 1989). Overcrowding may increase the amount of stress birds are subjected to and facilitate the transmission of diseases (Archibald et al. 1991). At Izumi the overcrowding of cranes has caused the government of Japan to investigate proposals to reduce the density of cranes by encouraging them to use other areas (Higuchi 1991). At both Poyang Lake and Izumi, tourism based on the exceptional bird life also increases human disturbance (Scott 1989) but may have more positive than negative effects on cranes when the survival of wildlife is essential for the continuation of tourism and associated financial gain.

Recommendations for Reserves and Their Boundaries

Although we consider it desirable for all areas utilized by cranes to be fully protected in nature reserves, our research identifies the following key areas where reserves should be established immediately or the boundaries of reserves currently in existence should be extended: Busan, the Korean DMZ (Cholwon, Panmunchom), Kumya, Lake Khanka–Xinghai, Poyang Lake, the Three Rivers (Sanjiang) Plain, Sonbon, and the Yellow River Delta–Bohai Bay. Further, given the international nature of crane research and conservation, an internationally available directory showing the boundaries of protected areas in countries inhabited by cranes in global standard coordinates would be helpful for identifying conservation priorities. Although point locations of reserves in Asia have been published in relatively accessible venues (Scott 1989; Ma & Li 1994; Harris et al. 2000), in most cases, materials identifying the boundaries of reserves are not readily available. Because satellite locations are delivered in latitude and longitude, delineating reserve boundaries similarly, with updates available when appropriate, would assist in determining when location data fall in reserved areas and when they do not. This would also facilitate our recommendations to modify reserve boundaries (Higuchi et al. 1996). Finally, when satellite location data are used to identify important areas for birds or other animal species with the aim of delineating boundaries for nature reserves, locations must be complemented by ground-based research because of limitations in accuracy imposed by margins of error inherent in satellite location data (Keating et al. 1991; Hays et al. 2001).

Constraints on Satellite-Based Research

In terms of logistic and technical limitations of satellite telemetry, its expense precludes large sample sizes, and technical problems—such as transmitters becoming detached from animals, the relatively short length of battery life, and premature battery failure—are not uncommon. Solar-powered transmitters are available, and these last longer than transmitters powered by conventional batteries. Because temporal variation in wetland conditions can be significant, caution must be exercised when drawing conclusions from very short-term studies, and longer-lasting transmitters would be especially valuable for this reason. To help address limitations on research imposed by the cost of satellite telemetry, part of the revenue collected from tourism based on study animals could be directed into their conservation, including research. This is particularly important in locations such as China and Russia, where research funding is scarce (Zhang 1994; Y. Darman, personal communication). When research does occur, it tends to be local rather than coordinated across wider geographic areas. Also, research tends to be temporally disjunct, with few continuous, long-term studies being conducted (Zhang 1994). Therefore, revenue derived from tourism generated by cranes at Poyang Lake, for example, could be critical for research on cranes to occur in China. Also, such funding could be applied to establishing or assisting ongoing conservation programs.

Cranes as Umbrella Species

Habitats occupied by cranes are also used by other wildlife, including birds, mammals, and fishes, and the research and revenue applied to the conservation of cranes may benefit these other species. For example, Panmunchom is an important site for ducks and geese as well as cranes, and it was formerly used by the critically endangered Crested Ibis (*Nipponia nippon*). Herons and birds of prey also frequent the area (Scott 1989, Chong & Morishita 1996). Similarly, the Yellow River delta is an extremely important wildlife area for ducks, geese, gulls, grebes, herons, shorebirds, storks, and the threatened Great Bustard (*Otis tarda*) (Zhao & Song 1995; BirdLife International 2001). In addition, almost 90 species of fishes and 50 species of terrestrial vertebrates other than birds have been recorded there (Scott 1989). Thus, cranes may be good umbrella species for the conservation of other members of ecosystems, especially waterfowl because of the similarities of the two groups' habitats. Further, the protection of birds' and other animals' habitats will preserve nontarget organisms such as plants, as well as the integrity of biological systems in general (Schoff 1991).

Although cranes share their habitats with many water birds and satellite tracking has been used on cranes for about 10 years in Asia, little satellite-based research has been done on other Asian waterfowl and wetland birds (Higuchi et al. 1991; Higuchi et al. 2000; Javed et al. 2000; Takekawa et al. 2000). This lack of research means that the locations of breeding ranges, migration routes, staging areas, and nonbreeding sites are unknown (Asia-Pacific Migratory Waterbird Conservation Committee 2001), rendering potential conservation efforts difficult or impossible for these species. These knowledge deficits could be addressed in part by satellite-tracking research, which would benefit the conservation of tracked species.

Broader Applications of Satellite Location Data

Beyond primary applications of satellite-tracking data, such as simply plotting animal locations and movement trajectories and identifying important staging, resting, and wintering areas, researchers are using increasingly sophisticated analyses and broadening the application of data. For example, investigators may use multiple data layers with animal location data to increase the scope of their analyses. One such study is that by Ueta and Higuchi (2002), who overlaid location and demographic data to compare differences between juvenile and adult migration patterns in three species of birds. Further, researchers are increasingly combining more conventional satellite-based studies of animal movements with modeling and hypothesis testing (Harrington & Veitch 1992; Luschi et al. 2001; Barlow et al. 2002). The sophistication of analyses is expected to continue to increase, as it has since the inception of satellite tracking itself.

International Cooperation and Education

Because long-distance migrants do not follow political borders, and ground-based research is a valuable complement of satellite-based work, international collaboration and cooperation among scientists and governments is necessary to maximize the research and conservation value of satellite-tracking studies. We tracked cranes through several countries whose politics are in flux and among whom relationships can be tense. Despite these obstacles, collaboration and cooperation is possible, as demonstrated by the establishment of an international wildlife refuge at Lake Khanka–Xinghai (Harris et al. 2000) and the work of international organizations to conserve migratory water birds (e.g., BirdLife International and Wetlands International). Publications on satellite tracking in Asia are often coauthored by U.S., Chinese, Japanese, Korean, and Russian scientists (e.g., Chong et al. 1994; Higuchi et al. 1994*a*; Harris et al. 2000).

Beyond informal communications between scientists and the publication of conservation research, dissemination of information to the public is expected to enhance awareness of important threats and conservation efforts. The internet provides an exceptionally effective forum through which to expose conservation efforts globally and inexpensively, including those facilitated by satellite-tracking data. For example, Space Today Online maintains an excellent website with links to satellite-tracking research involving many different organisms (www.spacetoday.org/satellites/tracking/resources.html).

The Future

The importance and utility of satellite technologies as tools in conservation research is certain to increase in the future because of the development of increasingly sophisticated hardware and data-gathering methodologies. Gathering data over large scales should encourage the development and implementation of conservation programs integrated over the ranges of study populations. Such integrated networks of protected areas are critical for the long-term conservation of long-distance migratory species.

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Appendix 1. Main areas visited by White-naped Cranes on migration, as determined by satellite-tracking between 1991 and 1994.[a]

Crane identification no. (year tracking began)	*Country*	*Locality[b]*	*Latitude(°)*	*Longitude(°)*	*Habitat*	*Approx. length of stay (days)*	*Kind of use*	*Area included in nature reserve?[b]*
9377 (1991)	China	Bohai Bay	39.12	118.49–118.50	coastal marsh	1	resting	n
	China	Yellow River near Bohai Bay	37.69–37.87	118.53–118.89	marsh, river, plain	20	resting	y
	China	Tuo River, N of Bengbu	33.49	117.27	plain, river	1	resting	u
	China	near Wabu Lake	32.07	116.80	plain	1	resting	n
	China	Poyang Lake	28.95–29.85	115.86–116.70	lake, and plains, rivers surrounding lake	42+	wintering	y
9374	China	near Wulagai River	45.46–45.49	118.49	marsh	1	resting	n?
	China	near Beng River	42.20	119.70	plain	1	resting	u
	China	Tianjin	39.21–39.62	117.86–118.29	plain, river	1–2	resting	u
	China	near Yellow River mouth Laizhou Bay	37.68–37.69	118.98–118.99	marsh	1	resting	n
	China	Longcheng	34.01	117.37	plain	1	resting	u
	China	S of Pi River	31.15–31.20	116.18–116.19	mountains (near lake)	1	resting	u
	China	Tai Lake	30.32–30.52	116.24–116.39	lake	10+	wintering	u
9375	China	near Wulagai River	45.59–45.99	118.20–118.66	river, marshes	1–2	resting	n?
	China	Xar Moron River	43.28–43.32	119.62–119.73	river, plain	1	resting	u
	China	SE of Tangshan	39.21–39.34	118.80–118.81	plain, river	1–2	resting	n
	China	Yellow River mouth	36.78–37.44	118.93–119.20	marsh, bay	3–4	resting	y
	China	N of Hongze Lake	33.77	118.54	plain, river	1	resting	n?
	China	Cao Lake	31.60	117.51	lake	1	resting	n
	China	Poyang Lake	28.86–29.87	115.92–116.60	lake, and plain and rivers surrounding lake	60–61+	wintering	y
9377 (1992)	Russia	near Bureya River	48.97–48.99	130.12–130.14	river, floodplain	2	resting	u
	China	Three Rivers Plain	46.83–46.91	132.86–133.09	marsh, agricultural fields, grassland	21	resting	n
	Russia	Lake Khanka	44.50–44.70	132.18–132.52	lake and surrounding marsh	3	resting	y?
	Korean Peninsula	demilitarized zone	37.83–38.08	126.70–127.04	river, marsh, peninsula vegetated areas	13	resting	u
	Japan	Izumi	31.75–32.38	129.45–131.31	agricultural fields	31+	wintering	y

Appendix 1. (continued)

Crane identification no. (year tracking began)	*Country*	*Locality*[b]	*Latitude(°)*	*Longitude(°)*	*Habitat*	*Approx. length of stay (days)*	*Kind of use*	*Area included in nature reserve?*[b]
20247	China	Xar Moron River	43.36–43.44	120.83–120.93	river	6–7	resting	u
	China	N Xiawa	42.80–42.92	120.56–120.65	river	1–2	resting	u
	China	S Tangshan	39.35–39.37	118.12–118.20	plain (near sea)	7–8	resting	u
	China	E Tianjin	39.19–39.39	117.20–117.34	plain (near river)	28–29	resting	n
	China	SW Bohai Bay	38.13–38.15	117.56–117.63	plain (near river)	2–3	resting	y
	China	N Zhangdian	37.24–37.27	117.71–117.93	plain (near river)	1–2	resting	u
	China	Linyi	34.86	118.29	plain (near river)	1–2	resting	y
	China	Huainan	32.59–32.56	116.74–116.75	plain (near river)	1	resting	u
	China	WNW Bengbu	33.11–33.46	116.52–117.33	plain, river	17+	wintering	u
20248	China	E Choybalsan	48.23–48.28	114.90–115.00	plain	7	resting	u
	China	N Wudan	43.23–43.64	118.66–118.92	river	1–2	resting	u
	China	N Shanhaiguan	40.67–40.68	119.80–119.83	mountain	1	resting	u
	China	S Tangshan	39.15–39.25	118.25–118.31	plain (near sea)	1–2	resting	n
	China	Yellow River	37.76–37.84	118.90–119.01	marsh	1	resting	y
	China	Yunhe	34.26	117.77	plain	1	resting	u
	China	SE Bengbu	32.74–32.81	117.61–117.76	plain	1	resting	u
	China	near Wabu Lake	32.47–32.62	116.72–116.79	plain (near lake)	7	resting	n
	China	Poyang Lake	29.07–29.25	115.89–116.11	lake	49+	wintering	y
20250	China	SW Hu-Lun Lake	48.09	116.34	plain	1	resting	n?
	China	NW Han Ul	44.92–44.97	118.35–118.40	marsh	1	resting	u
	China	Xar Moron River	43.24–43.29	119.62–119.76	river	1–2	resting	u
	China	Nailin	41.88	119.23	plain	1	resting	u
	China	Shanhaiguan	40.21–40.39	119.87–120.17	plain (near sea)	2–3	resting	u
	China	SE Tangshan	39.26	119.08	plain (near sea)	1	resting	n
	China	W Bohai Bay	38.57–38.59	117.47–117.48	plain (near sea)	1	resting	n
	China	Yellow River	37.79–37.84	118.55–118.91	marsh	1	resting	y
	China	SW Linyi	34.66–34.81	117.91–118.01	plain (near river)	3	resting	u
	China	N Huainan	33.11–33.15	116.77–116.80	plain	1	resting	u
	China	near Wabu Lake	32.49–32.63	116.50–116.78	plain (near river)	17–18	resting	u
	China	W Auqing	30.66	116.75–116.77	marsh	1	resting	u
	China	Poyang Lake	28.86–29.47	115.81–116.42	lake	31+	wintering	y
20252	Mongolia Russia	S Ozero Barun-torey	49.93–50.00	115.32–115.47	plain (near lake)	29–30	resting	y
	China	S Hu-Lun Lake	48.44–48.48	117.21–117.26	plain (near lake)	1	resting	y
	China	SE Hu-Lun Lake	48.23–48.30	117.59–117.69	plain (near lake)	2	resting	y?
	China	Laoha River	42.42–42.56	119.43–119.63	river	3	resting	u
	China	S Tangshan	39.26–39.45	118.14–118.28	plain (near sea)	8–9	resting	u
	China	Tianjin	39.10–39.31	117.21–117.36	plain	29–30	resting	n
	China	SW Bohai Bay	38.04–38.15	117.62–117.86	plain (near river)	4	resting	y
	China	Binzhou	37.49–37.65	118.03–118.29	plain (near river)	9	resting	u
	China	W Teng Xian	34.97–35.01	116.84–116.96	plain (near lake)	1–2	resting	u
	China	W Yingshang	32.64	115.98	marsh	1	resting	u
	China	NE Dagian Lake	29.80–30.33	116.43–117.17	lake and river	18+	wintering	n
20253	Mongolia Russia	S Ozero Barun-torey	49.83–50.10	115.48–115.78	marsh (near lake)	52–53	resting	y
	China	Huhur River	44.15–44.21	120.34–120.52	plain	1	resting	u
	China	Baixingt	43.35–43.42	120.79–121.05	river	6–7	resting	u
	China	N Jinxi	41.24	120.57	plain	1	resting	u
	China	S Tangshan	39.21	118.29–118.35	plain (near sea)	1–2	resting	u
	China	W Bohai Bay	38.58–38.63	117.43–117.50	plain (near sea)	1	resting	n
	China	Yellow River	37.74–37.81	118.83–118.99	marsh	22–23	resting	y
	China	Jining	35.43–35.52	116.46–116.53	plain	1	resting	u
	China	Fuliji	33.76–33.80	116.74–116.96	plain	1	resting	u
	China	W Fuyang	33.60	115.55	plain	1	resting	u
	China	Poyang Lake	29.07–29.30	115.91–116.18	lake	21+	wintering	y
20271	China	N Xcheng	47.29–47.31	131.10–131.12	river	1	resting	n
	China	Three Rivers Plain	46.83–46.84	132.72–132.77	plain	1	resting	n
	Russia	S Fujin	47.03–47.04	131.92–131.93	plain	1	resting	u
	Russia	Lake Khanka	44.94–45.05	132.89–133.05	lake	21	resting	y?
	Russia- China-North Korea	Sonbon	42.39–42.40	130.69–130.71	mouth of river	1	resting	u
	North Korea	Odaejin	41.35	129.73	mouth of river	1	resting	u
	North Korea	Tanch'on	40.47	128.99–129.01	mouth of river	1	resting	u
	North Korea	Sondok	39.40–39.91	127.48–127.75	marsh	3	resting	u
	South Korea	Cholwon	38.26–38.34	127.15–127.24	plain	22	resting	n
	South Korea	W Busan	35.33–35.35	128.66–128.69	river	1	resting	n
	Japan	Fukuoka Prefecture	33.57	130.72	river	1	resting	u
	Japan	Izumi	32.02–32.20	130.15–130.40	plain	26+	wintering	y
20273	China	N Bei'an	48.55–48.59	126.76–126.90	plain (near river)	4	resting	u
	China	NE Baicheng	46.20–46.45	123.79–124.43	marsh	2	resting	y
	China	Qingyuan	42.13	124.93	plain	1	resting	u
	North Korea	E Hwangju	38.58	126.06	plain	1	resting	u
	North/South Korea	Panmunchom	37.84–38.02	126.60–126.74	marsh	25–26	resting	n
	Japan	Fukuoka Prefecture	33.33–33.36	130.54–130.62	river	1–2	resting	u
	Japan	Izumi	32.06–32.15	130.18–130.33	plain	38+	wintering	y

[a]*Some location data on four cranes is presented in Higuchi et al. (1994a). Locations obtained from birds assumed to be in flight excluded.*
[b]*Abbreviations: N, north; S, south; W, west; E, east; n, no; u, unknown; y, yes; ?, conservation status of location uncertain (e.g., because a reserve is recorded as proposed in the area or the area may be included in a reserve recorded in the literature only by name and general location or one latitudinal/longitudinal point).*