Mem. Natl Inst. Polar Res., Spec. Issue, **58**, 101–109, 2004

Review

Satellite tracking in avian conservation: applications and results from Asia

Johanna P. Pierre[1, 2] and Hiroyoshi Higuchi[1]*

[1]*Laboratory of Biodiversity Science, School of Agricultural and Life Sciences, University of Tokyo, Yayoi 1-chome, Bunkyo-ku, Tokyo 113-8657 (*higuchi@es.a.u-tokyo.ac.jp)*
[2]*Present address: Conservation Services Programme, Department of Conservation Science and Technical Centre, P.O. Box 10-420, Wellington, New Zealand*

(Received March 21, 2003; Accepted September 1, 2003)

Abstract: Using satellite tracking, we have followed the movements of large wetland birds in Asia for more than 10 years. We have investigated the migration patterns of more than 10 species of birds, focusing on, but not limited to, cranes (Gruidae) and storks (Ciconiidae). To relay bird locations, we employed platform transmitter terminals in combination with ARGOS satellites. Location data were then utilized in a variety of applications, from determining migration routes, stopover patterns and wintering sites, through more advanced analyses including using various data overlays to examine habitat use, occupation of nature reserves, differential migration patterns between adults and juvenile birds, climatological effects on migration and the connectivity and network structure of migration pathways. Through this work, we have identified numerous important sites for migratory birds, especially cranes and storks. These include Bohai Bay and the Yellow River delta (China), the Korean Demilitarized Zone, Lake Khanka (Russia/China), and Poyang Lake, the Qiqihar Baicheng area, the Three Rivers Plain and Yangcheng Nature Reserve (all in China). We have also developed recommendations for spatial improvements to nature reserves, discovered different migration strategies in juvenile and adult birds, and a possible migration trigger involving temperature. We emphasize the importance of continued empirical research and development of analytical methodologies involving satellite location data. Further, we advocate the protection of habitats used by Gruidae and Ciconiidae over their entire migration routes.

key words: satellite tracking, Gruidae, Ciconiidae, Asia, conservation

Introduction

Satellite-based technologies have been used in the field of wildlife research for approximately 20 years. In this field, important applications of these technologies include monitoring animal movements at landscape to global scales and assessing habitat characteristics (*e.g.* Fancy *et al.*, 1988; Priede and Swift, 1992; Tamura *et al.*, 2000; references below). Key advantages to using satellites as research tools include the large spatial scales data can be recorded over, which exceed, for example, the range capabilities of more traditional telemetry systems. Further, remote data collection allows investigators to take a hands-off approach to research, except for the initial attachment of transmitters to study animals. Since they were first introduced as tools for wildlife research, the use of satellite-based technologies has increased dramatically, and the application of these techniques is now commonplace.

In Asia, ornithologists have been conducting research utilizing satellite technologies for approximately 10 years (Higuchi *et al*., 1991, 1992). The technique is especially well suited to Asian-based research because of the extremely large land area, sensitive political situation, and preponderance of urgent conservation problems in the region. Movements of about 15 species have been investigated using satellite tracking in Asia, and study species have included cranes (Gruidae), storks (Ciconiidae), swans and geese (Anatidae), and buzzards and sea-eagles (Accipitridae).

Research using satellite tracking commenced in our laboratory in 1990, with an investigation of the migration patterns of the whistling swan, *Cygnus columbianus* (Higuchi *et al*., 1991). The goal of this research was to identify migration routes used by this swan, to facilitate conservation efforts and arrest the decline of swans and loss of their habitats. Since this time, our research has continued to focus on species of conservation concern. Thus, the objective of our more recent research is to investigate migration routes, migration patterns and habitat use of vulnerable, threatened and endangered birds in Asia, with the aim of contributing to the conservation of these birds and their habitats.

In this paper, we briefly review our recent research utilizing satellite tracking to investigate the movements of threatened and endangered birds around Asia. We focus mainly on our studies of members of the Gruidae and Ciconiidae families, and examine our work in terms of applications for satellite data at primary, secondary and tertiary analytical levels. Primary analyses are limited to the basic determination of migration routes, timing of migration, and the locations of stopover and wintering sites. Secondary analyses involve an additional data layer, such as landcover maps to identify habitats used by tracked birds, or demographic information to investigate differences between adult and juvenile migration patterns. Finally, we examine tertiary, *i.e*. multi-layered data analyses, as well as more complex applications encompassing modeling and hypothesis testing within data matrices. Examples of these applications may include the effects of landscape structure and climate on migration, and analyses of the connectivity of habitat patches, and migration nodes and networks.

Methods

In conjunction with many colleagues, we have captured various species of the Gruidae and Ciconiidae families on their breeding and wintering grounds in Russia and Japan. Birds were captured with the aid of helicopters, cannon nets, or by scattering wheat coated with the oral tranquilizer alpha-chloralose (Kanai *et al*., 2000). We attached legbands to all birds captured, as well as satellite transmitters. Transmitters were attached using Teflon ribbon harnesses (Nagendran *et al*., 1994).

Satellite transmitters (platform transmitter terminals, or PTTs) attached to birds were made by NTT Corp. and Toyo Communication Equipment Co. in Japan, and Microwave Telemetry in the U.S.A.. PTTs ranged in weight from 30–80 g, and were never more than 2% of the target species' body weight (*e.g*. Higuchi *et al*., 1996, 1998; Kanai *et al*., 1997). For all species, we set PTTs to cycle 6 hours on and 12 hours off. We used ARGOS satellites to receive satellite locations, and downloaded location data as Location Classes 0–3, A, B, and

Z. We focused analyses on data of location classes 0–3, with class 3 being the most accurate (Keating *et al*., 1991; Service ARGOS, 1994). When points in other location classes fell along migration routes determined by class 0–3 data, we included them in analyses also.

Location data obtained *via* satellite tracking have been incorporated into multi-layered analyses, at the primary through tertiary levels, as described above. In this review, we will not discuss the more complex methodologies leading to the emergence of final results at each of these levels. Instead, we provide references to original publications containing this more detailed information.

Results and discussion

Over all, we have successfully delineated some of the migration routes of more than 11 species of birds in Asia, including the common crane (*Grus grus*), red-crowned crane (*G. japonensis*), Siberian crane (*G. leucogeranus*), white-naped crane (*G. vipio*), demoiselle crane (*Anthropoides virgo*), oriental white stork (*Ciconia boyciana*), whistling swan (*Cygnus columbianus*), white-fronted goose (*Anser albifrons*), whooper swan (*Cygnus cygnus*) and grey-faced buzzard (*Bustatur indicus*). As mentioned above, we will focus on cranes (Gruidae) and storks (Ciconiidae) here.

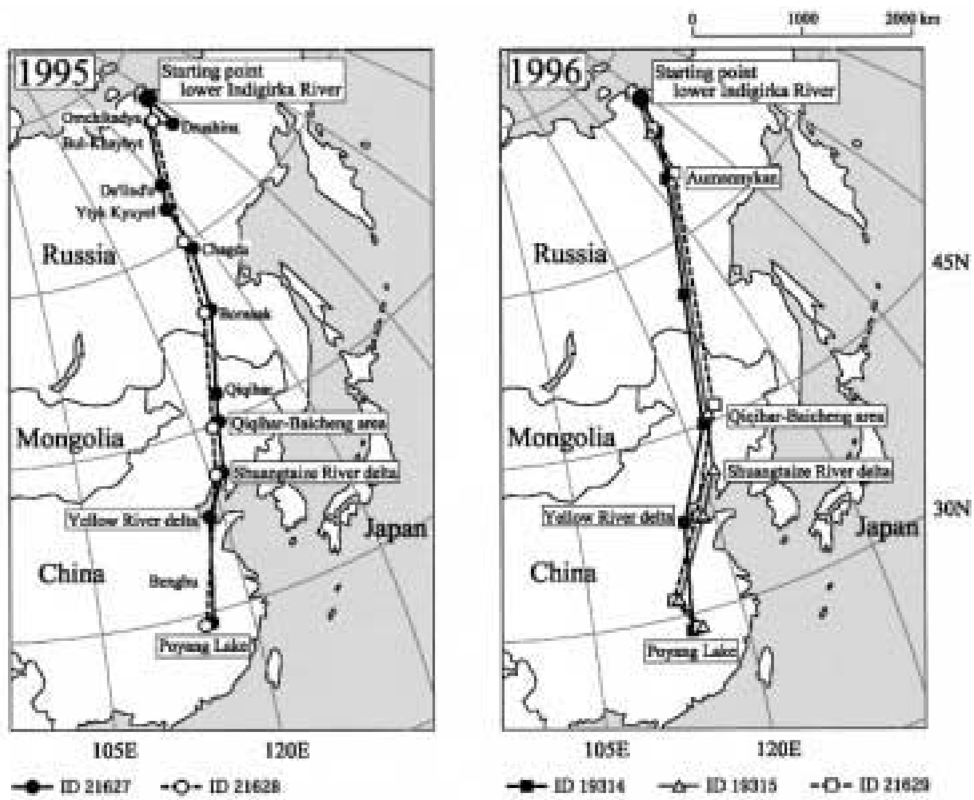

Fig. 1. Migration routes of Siberian cranes satellite-tracked from northeastern Siberia. (From Kanai *et al*., 2002).

Primary level analyses

Cranes and storks covered highly variable distances on migration, both within and between species. For example, red-crowned cranes migrated from 871–2509 km between their breeding and wintering sites (Higuchi *et al*., 1998; Tamura *et al*., 2000). Siberian cranes migrated the furthest of all crane species we have tracked, covering 4903–5586 km between their breeding and wintering areas (Kanai *et al*., 2002, Fig. 1).

In accordance with distances covered, the detected number of rest stops taken by migrating cranes ranged from 0–17. Red-crowned cranes may have been able to migrate without resting (Tamura *et al*., 2000). White-naped cranes were able to complete their migration with as few as one rest stop (Higuchi *et al*., 1996), while Siberian cranes took the most rest stops of any species tracked (Kanai *et al*., 2002). In short, cranes appeared to make the longest flights possible between rest stops. For demoiselle cranes, this may be necessary due to the fairly inhospitable nature of habitats along their migration pathways (Kanai *et al*., 2000). However, migration routes of other species cover less extreme habitats, which suggests that traveling as far as possible as quickly as possible is strategic, rather than necessary.

Migration strategies appeared to differ between cranes and oriental white storks. Cranes took fewer lengthy rest stops than oriental white storks. Most cranes rested for more than 6 days only 1–5 times during migration, whereas storks spent an average of 20 days at each of their 3–6 rest stops. Further, storks made much shorter daily flights than cranes (Higuchi *et al*., 2000; Tamura *et al*., 2000; Shimazaki *et al*., 2004). This difference between the migration strategies of cranes and storks may be related to fat storage. Cranes tend to store fat, whereas storks may not (Berthold *et al*., 2001a). Further, if the lack of protein accumulation found in white storks (*Ciconia ciconia*) (Michard-Picamelot *et al*., 2002) extends to oriental white storks, this is also expected to determine migratory patterns.

Although migrating cranes and storks took variable numbers of rest stops, both within and among species, we have successfully used satellite tracking data to identify particularly important stopover sites. These include: Aumannykan area (Russia, Siberian cranes, Kanai *et al*., 2002), the Korean Demilitarized Zone (hooded and white-naped cranes, Higuchi *et al*., 1996, 2004, unpubl. data), Lake Khanka, China, Russia (white-naped cranes, Higuchi *et al*., 1996, 2004), Liaodong and Bohai Bays, China (red-crowned and white-naped cranes, and oriental white storks, Higuchi *et al*., 1996, 1998, 2000, 2004; Shimazaki *et al*., 2004; Tamura *et al*., 2000), the Three Rivers Plain, China (white-naped cranes, Higuchi *et al*., 1998, 2004), Tianjin, China (white-naped cranes, Higuchi *et al*., 1998, 2004), the Yellow River delta, China (red-crowned, Siberian and white-naped cranes, Higuchi *et al*., 1996, 1998, 2004; Tamura *et al*., 2000; Kanai *et al*., 2002), the Qiqihar Baicheng area, China (Siberian cranes, Kanai *et al*., 2002), Shuantaizi River delta, China (Siberian cranes, Kanai *et al*., 2002), Tumen River mouth, Russia, North Korea (red-crowned cranes, Higuchi *et al*., 1998; Tamura *et al*., 2000), Odaejin-nodonjagu, North Korea (red-crowned cranes, Higuchi *et al*., 1998; Tamura *et al*., 2000).

Satellite tracking research continues to identify previously unknown wintering sites used by migratory birds (*e.g*. Berthold *et al*., 2001b). Our work shows the following wintering sites to be particularly important: Izumi, Japan (hooded and white-naped cranes, Higuchi *et al*., 1996, 2004, unpubl. data), the Korean Demilitarized Zone (white-naped and red-crowned cranes, Higuchi *et al*., 1998; Higuchi and Minton, 2000; Tamura *et al*., 2000), Kumya and Anbyon, North Korea (red-crowned cranes, Higuchi *et al*., 1998; Higuchi and

Minton, 2000), Poyang Lake, China (oriental white storks, white-naped and Siberian cranes, Higuchi *et al*., 1996, 2000, 2004; Kanai *et al*., 2002; Shimazaki *et al*., 2004), Yangcheng Nature Reserve, China (red-crowned cranes, Higuchi *et al*., 1998; Tamura *et al*., 2000), and the Yangtze River floodplains (*e.g*. Dongting and Shenjin Lakes, oriental white storks, Higuchi *et al*., 2000; Shimazaki *et al*., 2004).

Secondary level analyses

Using satellite tracking to investigate migration patterns, *i.e*. routes, stopover sites and durations, and identify wintering sites, is now routine in wildlife research. However, combining basic migration data with additional data layers is less common, and yields more powerful analyses for conservation purposes. In this vein, Tamura *et al*. (2000) overlaid satellite-generated landcover maps and satellite locations of red-crowned cranes and oriental white storks to investigate habitats occupied by the two species. Overlays showed that in the Russian part of the species' range, birds occupied natural wetlands most frequently. However, in China, both species were most often located in farmland, rather than wetland habitats (Fig. 2, 3). Tamura *et al*. (2000) attributed this to the scarcity of natural wetlands in China due to anthropogenic development.

An additional, and specifically conservation-oriented application of secondary analysis involves overlaying bird locations and the boundaries of prospective or currently existing nature reserves. For example, the effectiveness of nature reserves in the south of Bohai Bay around the Yellow River delta, and at Poyang Lake, has been investigated by overlaying the satellite-generated locations of white-naped cranes and reserve boundaries (Higuchi *et al*., 2004). In both areas, significant numbers of locations fell outside reserve boundaries, identifying a need for the expansion of existing nature reserves, and the creation of new reserves in several key sites in the two areas. Further, because there is interannual variation in spatial habitat utilization by cranes and storks (Tamura *et al*., 2000), studies aiming to identify appropriate reserve boundaries using any form of location data should be conducted over multiple years. This caveat also applies to investigations of habitat use, mentioned above.

The final example of secondary analysis we will examine here involves overlaying location data with demographic data. Because we have satellite tracked birds of mixed age and sex, it is possible to investigate the differences in migration patterns between these population strata. Ueta and Higuchi (2002) analyzed the migration patterns of Steller's sea-eagles (*Haliaeetus pelagicus*), black-faced spoonbills (*Platalea minor*) and white-naped cranes as determined by satellite tracking, in accordance with the ages of tracked birds. They found that during the spring migration, there were no significant differences between juvenile and adult birds, in terms of the total migration distance and the distance between stopover sites. However, the duration of migration and the length of rest stops were both longer in immature birds. This is hypothesized to be the result of young birds aiming to maximize their body condition by enhancing their fat stores through spending more time foraging at rest stops (Ueta and Higuchi, 2002).

Tertiary level and complex data analyses

At the tertiary level of data analysis, a potential avenue for future investigation is the relationship between climatological variables and bird migration. Kanai *et al*. (2002) speculated on the relevance of climate to migration, due to their finding that in both years of their

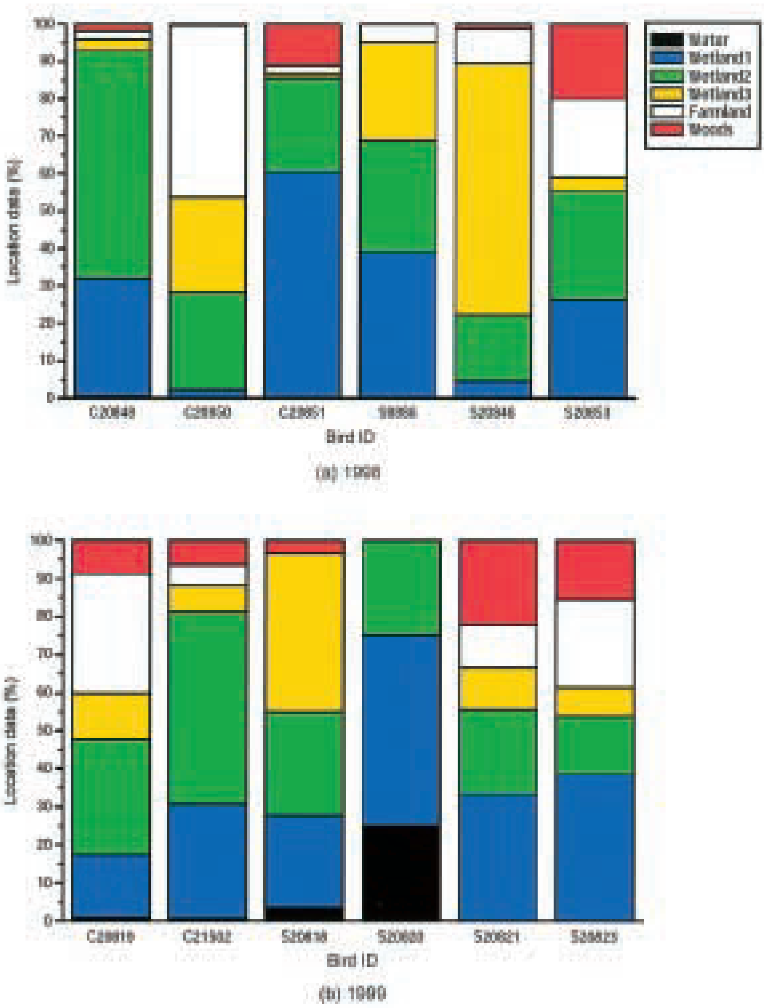

Fig. 2. Percentage of bird locations in each landcover type in the Amur River basin, Russia. (a) 1998, (b) 1999. C = red-crowned cranes, S = oriental white storks. (From Tamura *et al*., 2000).

study, Siberian crane migration commenced following temperatures of –5°C. Investigating the effects of topographic landscape structure on migration may also be fruitful, with digital data relatively readily available *via* remote sensing.

At any level of analysis involving satellite tracking data, the use of modeling and defined hypothesis tests, rather than simple qualitative descriptions of migration patterns, is increasing though still relatively uncommon worldwide. In Asia, these approaches are in their infancy. One recent example of hypothesis testing based on migration data is described in Shimazaki *et al*. (2004), who investigated the connectivity and node structure of oriental white stork migration networks.

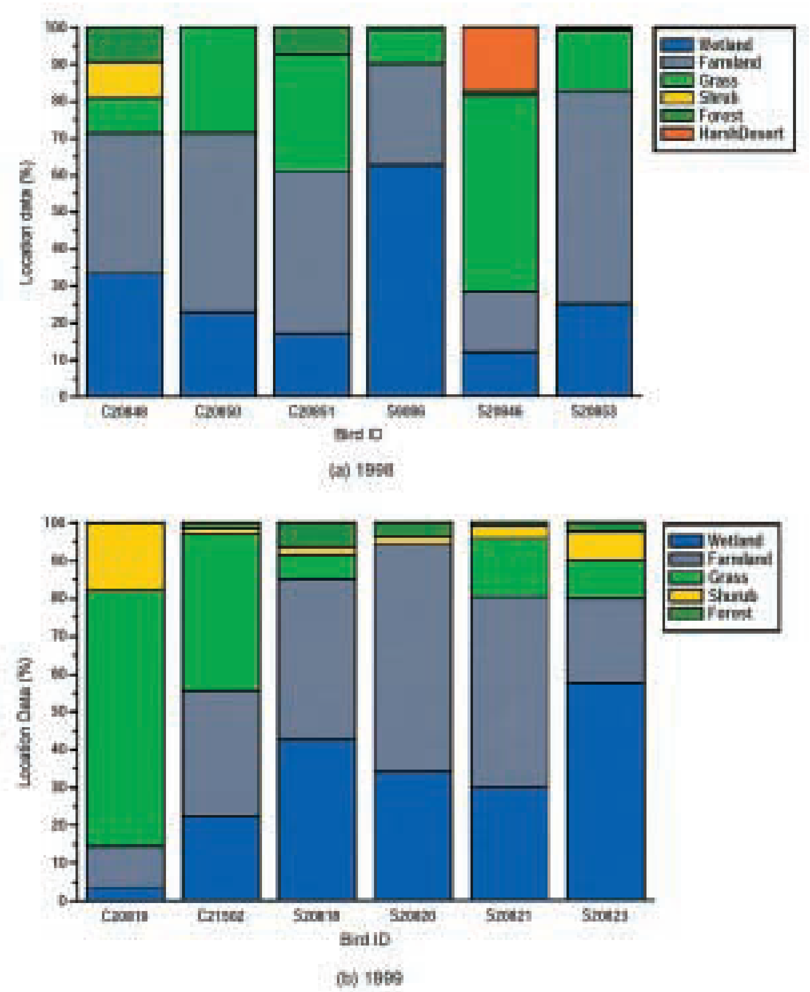

Fig. 3. Percentage of bird locations in each landcover type in China. (a) 1998, (b) 1999. C = red-crowned cranes, S = oriental white storks. (From Tamura *et al*., 2000).

Conclusion

Both satellite-based technologies and the analyses used to interpret them are continuously developing, and the emergence of new analyses will no doubt enhance opportunities for conservation research. In concert with methodological advances however, basic knowledge of migration patterns is still required for many species of birds whose breeding, stopover and wintering sites are unknown or poorly known. Further, basic knowledge and more advanced methodologies must be combined and applied to achieving conservation goals. Through our research, we have identified many important areas for large migratory birds in Asia. While the maintenance of research efforts is vital, the most critical step for conservation is preserving areas we already know the value of.

Acknowledgments

We do not have the space here to thank everyone who has contributed to the research described above, but would like to particularly acknowledge the field staff and helicopter pilots we have worked with, and the following people: V. Andronov, G. Archibald, B. Auyrsana, Y. Darman, G. Fujita, O. Goroshko, J. Harris, N. Germogenov, S. Javed, Y. Kanai, N. Kanmuri, A. Kovhsar, V. Krever, J. Minton, N. Mita, E. Morishita, M. Nagendran, K. Ozaki, M. Parilov, M. Soma, R. Suwal, M. Tamura, and M. Ueta. Figure 1, from Kanai *et al.* (2002), appears with permission from Elsevier Science. Figures 2 and 3 are reproduced courtesy of the Association of International Research Initiatives for Environmental Studies.

References

Berthold, P., Elverfeldt, D., Fiedler, W., Hennig, W., Kaatz, M. and Querner, U. (2001a): Magnetic resonance imaging and spectroscopy (MRI, MRS) of seasonal patterns of body composition: a methodological pilot study in White Storks (*Ciconia ciconia*). J. Ornithol., **142**, 63–72.

Berthold, P., van den Bossche, W., Fiedler, W., Kaatz, C., Kaatz, M., Leshem, Y., Nowak, E. and Querner, U. (2001b): Detection of a new important staging and wintering area of the white stork *Ciconia ciconia* by satellite tracking. Ibis, **143**, 450–455.

Fancy, S.G., Pank, L.F., Douglas, D.C., Curby, C.H., Garner, G.W., Amstrup, S.C. and Regelin, W.L. (1988): Satellite telemetry, a new tool for wildlife research and management. US Fish Wildl. Serv. Resour. Publ., **172**, 1–54.

Higuchi, H. and Minton, J. (2000): The importance of the Korean DMZ to threatened crane species in northeast Asia. Global Environ. Res., **4**, 123–132.

Higuchi, H., Sato, F., Matsui, S., Soma, M. and Kanmuri, N. (1991): Satellite tracking of the migration routes of whistling swans *Cygnus columbianus*. J. Yamashina Inst. Ornithol., **23**, 6–12.

Higuchi, H., Ozaki, K., Fujita, G., Soma, M., Kanmuri, N. and Ueta, M. (1992): Satellite tracking of the migration routes of cranes from southern Japan. Strix, **11**, 1–20.

Higuchi, H., Ozaki, K., Fujita, G., Minton, J., Ueta, M., Soma, M. and Mita, N. (1996): Satellite tracking of white-naped crane migration and the importance of the Korean Demilitarized Zone. Conserv. Biol., **10**, 806–812.

Higuchi, H., Shibaev, Y., Minton, J., Ozaki, K., Surmach, S., Fujita, G., Momose, K., Momose, Y., Ueta, M., Andronov, V., Mita, N. and Kanai, Y. (1998): Satellite tracking of the migration of the red-crowned crane *Grus japonensis*. Ecol. Res., **13**, 273–282.

Higuchi, H., Nagendran, M., Darman, Y., Tamura, M., Andronov, V., Parilov, M., Shimazaki, H. and Morishita, E. (2000): Migration and habitat use of oriental white storks from satellite tracking studies. Global Environ. Res., **4**, 169–182.

Higuchi, H., Pierre, J.P., Krever, V., Andronov, V., Fujita, G., Ozaki, K., Goroshko, O., Ueta, M., Smirensky, S. and Mita, N. (2004): Conservation using remote technologies: satellite-tracking white-naped cranes (*Grus vipio*) in Russia and Asia. Conserv. Biol., **18**, 136–147.

Kanai, Y., Sato, F., Ueta, M., Minton, J., Higuchi, H., Soma, M., Mita, N. and Matsui, S. (1997): The migration routes and important rest sites of whooper swans satellite-tracked from northern Japan. Strix, **15**, 1–13.

Kanai, Y., Minton, J., Nagendran, M., Ueta, M., Auyrsana, B., Goroshko, O., Kovshar, A.F., Mita, N., Suwal, R.N., Uzawa, K., Krever, V. and Higuchi, H. (2000): Migration of demoiselle cranes in Asia based on satellite tracking and fieldwork. Global Environ. Res., **4**, 143–153.

Kanai, Y., Ueta, M., Germogenov, N., Nagendran, M., Higuchi, H. and Mita, N. (2002): Migration routes and important resting areas of Siberian cranes (*Grus leucogeranus*) that migrate from northeastern Siberia and China as revealed by satellite tracking. Biol. Conserv., **106**, 339–346.

Keating, K.A., Brewster, W.G. and Key, C.H. (1991): Satellite telemetry: performance of animal-tracking systems. J. Wildl. Manage., **55**, 160–171.

Michard-Picamelot, D., Zorn, T., Gendner, J.-P., Mata, A.J. and Le Maho, Y. (2002): Body protein does not vary despite seasonal changes in fat in the white stork (*Ciconia ciconia*). Ibis, **144**, E1–E10.

Nagendran, M., Higuchi, H. and Sorokin, A.G. (1994): A harnessing technique to deploy transmitters on cranes. The Future of Cranes and Wetlands: Proceedings of the International Symposium, ed. by H. Higuchi and J. Minton. Tokyo, Wild Bird Society of Japan, 57–60.

Priede, I.G. and Swift. S.M. (1992): Wildlife Telemetry. Remote Monitoring and Tracking of Animals. London, Ellis Horwood, 708 p.

Service ARGOS Inc. (1994): User Manual. Toulouse, CLS/Service ARGOS.

Shimazaki, H., Tamura, M. and Higuchi, H. (2004): Migration routes and important stopover sites of endangered oriental white storks (*Ciconia boyciana*), as revealed by satellite tracking. Mem. Natl Inst. Polar Res., Spec. Issue, **58**, 162–178.

Tamura, M., Higuchi, H., Shimazaki, H., Oguma, H., Darman, Y.A., Andronov, V.A., Nagendran, M. and Parilov, M. (2000): Satellite observation of movements and habitat conditions of red-crowned cranes and oriental white storks in east Asia. Global Environ. Res., **4**, 207–217.

Ueta, M. and Higuchi, H. (2002): Difference in migration pattern between adult and immature birds using satellites. Auk, **119**, 832–835.