Landscape Ecol Eng
DOI 10.1007/s11355-010-0127-y

REPORT

Distribution, density, and habitat use of the Korean water deer (*Hydropotes inermis argyropus*) in Korea

Baek-Jun Kim · Dae-Hyun Oh · Seung-Hoon Chun · Sang-Don Lee

Received: 4 September 2009 / Revised: 10 June 2010 / Accepted: 23 July 2010

Abstract Water deer (*Hydropotes inermis*) belong to the genus *Hydropotes*, which is ecologically well adapted for environments ranging from desert to forest. Water deer tend to occupy the richest areas between forest and grasslands. There are two distinct subspecies in far East Asia: one in China (*H. inermis inermis*), and the other in Korea (*H. inermis argyropus*). Despite being listed as vulnerable on the International Union for Conservation of Nature (IUCN) Red List, little is known about the water deer. The species occurs in most areas of the Korean peninsula, except for Seoul and Jeju Island. Kyunggi Province near Seoul showed the lowest rate (56%) due to urbanization. There was a high difference in their presence between inland (81%) and coastal (60%) areas . In addition, large cities (67%) showed much lower rates than did rural areas (83%) where human population size is relatively low. Water deer are distributed differently based on habitat type, with differences in mean density observed among lowland (6.93 ind./km^2), mountainous (1.91), and urban (1.27) areas. There was also a difference in mean density between low-elevation and high-elevation areas. Finally, whereas the deer preferred landscapes with 20°–25° of slope and broadleaf forest ($P < 0.01$), they did not avoid areas with other types of slopes and habitats.

Keywords Distribution map · Elevation · Feces · Habitat type · Habitat use · Transect-line census

B.-J. Kim · S.-D. Lee (✉)
Department of Environmental Science and Engineering, College of Engineering, Ewha Womans University, Seoul 120-750, Korea
e-mail: lsd@ewha.ac.kr

B.-J. Kim
Conservation Genome Resource Bank for Korean Wildlife (CGRB), College of Veterinary Medicine and BK21 Program for Veterinary Science, Seoul National University, Seoul 151-742, Korea

D.-H. Oh
Ecosystem Survey Team, Nature Conservation Research Division, Environmental Resources Research Department, National Institute of Environmental Research, Incheon 404-708, Korea

S.-H. Chun
Department of Landscape Architecture, Kyungwon University, Songnam 461-701, Korea

Introduction

Water deer (*Hydropotes inermis*) inhabit temperate climates that experience frost and snow in winter. There are two distinct water deer subspecies (or populations) in far East Asia. One lives in China (*H. i. inermis* Swinhoe 1870) along the Yangtze River, and the other (*H. i. argyropus* Heude 1884) lives in Korea (Geist 1998). Exceptionally, a small number of individuals from the Chinese subspecies were introduced to the UK and France (Cooke and Farrell 1998). The genus *Hydropotes* is well adapted to various types of habitat. Water deer occupy the richest areas between forests and grasslands in temperate but not in warm climates (Geist 1998) and are most commonly found in dense grasses and reeds and often on shrubby slopes. Neither sex has antlers, but males have a pair of long, sharp canines, characteristics shared with the earliest deer species (Geist 1998). Geographically, *H. inermis* occurs close to the New World Arctic and Beringia, which was probably where all extant New World deer originated before the Pleistocene (Geist 1998).

Historically, the Chinese water deer (*H. i. inermis*) was abundant and extensively distributed throughout China

(Cooke and Farrell 1998). However, both its range and abundance have been greatly reduced due to habitat loss and illegal hunting for food and medicine (Wang 1998), and it is estimated that there are currently only about 10,000 water deer in the whole of China (Butzler 1990). Classified as vulnerable on the International Union for Conservation of Nature (IUCN) Red List (Harris and Duckworth 2008) and defined as vulnerable in China (Wang 1998), the Chinese water deer has been the subject of many recent ecological and genetic studies (Xu et al. 1999; Wang 1998; Zhu et al. 2004; Hu et al. 2006, 2007).

In contrast, the Korean water deer (*H. i. argyropus*) has been less studied (Lee 2003). It was once fairly abundant throughout Korea, inhabiting the ranges of Mt. Taebaek and Mt. Nangrim, in particular (Won and Smith 1999). Although this subspecies appeared to be locally abundant throughout most of its former range, its range and population size was seriously reduced due to excessive poaching and habitat destruction in the 1990s (Woo et al. 1990). The Korean water deer now occurs in a variety of wild habitats. It prefers dense forest and early successional vegetation and is therefore commonly found in lowland mountainous areas or riparian communities (Won and Smith 1999). Korean water deer are also frequently observed near agricultural areas (Won 1967), a habitat preference that causes serious conflicts between local farmers and the deer. To understand Korean water deer ecology, it is essential to first understand its distribution, density, and habitat use, especially as its population size has not yet been accurately estimated. In particular, information on distribution and density of wild animals is considered to estimate population dynamics related to global climate change (Marques et al. 2001). Furthermore, understanding patterns of habitat use is critical in developing effective management strategies, both in general as well as in the context of climate change (Marques et al. 2001).

The general purpose of this study was to address the fundamental ecology of the Korean water deer. Specifically, the three goals of the study were: (1) to present a qualitative distribution map and examine distribution patterns in South Korea; (2) to compare density in different habitat types and at different elevations; and (3) to analyze patterns of habitat use using geographic information system (GIS) techniques.

Materials and methods

Sampling sites

We designated three types of habitat: lowland (Pocheon City, Kyunggi Province; Cheorwon County, Kangwon Province), mountainous (Pocheon and Cheorwon), and urban (Dongnae-gu, Busan Metropolitan City, and Gimhae City, Kyungnam Province). Pocheon and Cheorwon tend to experience much less human disturbances than the other two cities (Dongnae and Gimhae). Kyungnam Province, on the other hand, has been actively developed and had a much higher population growth rate than Kyunggi and Kangwon Provinces during the last few decades.

Distribution

To determine Korean water deer distribution, we used previous survey data collected by field experts in the Korean peninsula over a 6-year period (Ministry of Environment of Korea 2000–2005). Data included qualitative results (e.g., presence or absence at survey sites) but not quantitative results (e.g., number of individuals observed at survey sites), because correct global positioning system (GPS) data was not available from the previous surveys (Ministry of Environment of Korea 2000–2005). All information on the presence or absence of deer (e.g., direct observation, indirect observation of feces or other tracks, and communication with local people) was used to make a distribution map. To analyze distribution patterns, we then counted the number of sites where the deer was present or absent and compared the proportions of deer presence under several factors (e.g., location, water availability, and human population size).

Density

To date, most habitat use analyses have used telemetry data. However, when telemetry is unavailable due to tracking problems, defecation distribution has been used to analyze cervid habitat use (Welch et al. 1990; Borkowski 2004). Whereas disadvantages to using defecation distribution have been reported (Collins and Urness 1981), other studies have shown similarities between results obtained from fecal deposit distribution and radio telemetry data (Guillet et al. 1995). Therefore, to compare water deer density in different habitats, we conducted a transect-line census of the number of fecal deposits during 2008 at three different target areas. All fecal deposits within 1 m of either side of the track were counted. Coordinates of all the fecal deposits were recorded using a GPS. Water deer density was then estimated using the following equation:

$$D[\text{ind./km}^2] = n \times 10^6/(Stf)$$

where n is the number of fecal deposits found on the plot, S is the size of the plot in m^2, t is the time (in days) of plot exposure, and f is the defecation rate of the species (Dobiáš et al. 1996). Kruskal–Wallis test was used to compare mean density among lowland, mountainous, and urban areas. Mann–Whitney U test was used to compare density between low and high elevations. We used only data from the feces census in the lowland and mountainous areas of Pocheon and Cheorwon, as we lacked GPS coordinates for fecal deposits in the other site.

Habitat use

To assess habitat use, we used the GPS coordinates from the fecal census in Cheorwon only (47 fecal deposits), as there were small sample sizes in the other sites. To determine slope-type preference, a contour map extracted from a topographical digital map (1:25,000) was converted into a slope map (Raster file, 10 m × 10 m pixel). The slopes were divided into six groups: 0°–4.99°, 5°–9.99°, 10°–14.99°, 15°–19.99°, 20°–24.99°, and ≥25°. All pixels through the transect-line for each survey were counted, and pixel counts were defined as expected (or available) frequency of each slope. Pixel counts of feces were defined as the observed frequency of each slope and analyzed by a chi-square test for goodness-of-fit of observed to expected slope type (Neu et al. 1974; Byers and Steinhorst 1984; White and Garrot 1990). This chi-square test was used to determine whether there was a significant difference between the expected utilization of slope types (based upon their availability) and the observed frequency of use (Byers and Steinhorst 1984). If significant differences were found, Bonferroni confidence intervals (BCI) were used to determine which slope types were preferred or avoided (Byers and Steinhorst 1984; Kiyota et al. 2005). CIs (*pi*) are defined as follows:

$$\hat{p}_i - z_{\alpha/2k}\sqrt{\hat{p}_i(1-\hat{p}_i)/n} \le p_i \le \hat{p}_i + z_{\alpha/2k}\sqrt{\hat{p}_i(1-\hat{p}_i)/n}$$

where $\alpha = 0.05$, $\hat{p}_i$ is the proportion of observed plots in slope type i, and $z_{\alpha/2k}$ is the upper standard normal variant corresponding to a probability tail area of $\alpha/2k$; k and n are the number of slopes and the total number of observed plots, respectively. We compared expected proportions with CIs. To determine habitat type preference, the land-use map (1:25,000) was digitized and converted into a Raster map (10 m × 10 m). After modification, the map was categorized into eight habitat types: residential area, broadleaf forest, coniferous forest, mixed forest, agricultural area, paddy field, grassland, and bare land. Habitat use analyses were then carried out with ArcMap version 9.3 (ESRI Inc., USA) with the same method used for slope-type analysis. Both descriptive and nonparametric statistics were used with SPSS version 12.0 (SPSS inc., USA).

Results

Distribution

Except for Seoul and Jeju, Ulleong, Dok, and other islands, water deer occur in most areas of the Korean peninsula (Fig. 2). They were least common in Kyunggi, where they were found in 56% of the province. They occurred in 76–92% of all other provinces (Fig. 2). Deer distribution was also different among habitat types (Fig. 2). They were found in about 81% of inland areas but only in 60% of coastal areas and islands (Fig. 2). They occurred less commonly in large cities [(67%; metropolitan city, population size = about 1,045,000–9,820,000 (71%) and city, about 52.000–1,069.000 (66%)] than in rural areas [county, about 20,000–137,000 (83%)], where human population size is lower (Ministry of Construction and Transportation 2007; Fig. 2).

Density

One hundred seventy fecal deposits were found in the three habitats ($n = 101$, 60, and nine fecal deposits in lowland, mountainous, and urban areas, respectively; Table 1). Mean densities in lowland, mountainous, and urban areas were 6.93 ± 7.94, 1.91 ± 1.53, and 1.27 ± 0.95 ind./km^2, respectively (Table 1), but there was no significant difference among the three habitats (Kruskal–Wallis test, $df = 2$, $P = 0.09$). To estimate density among different elevations, we included only lowland (low elevation) and mountainous (high elevation) area in Pocheon and Cheorwon due to small sample sizes in the other habitats (Table 1). Whereas the lowland area tended to show higher mean density than the mountainous area, mean density was not significantly different between the two areas [Mann–Whitney U test, $n = 8$ (lowland) and 12 (mountainous), $P < 0.10$]. However, at the level of $\alpha = 0.10$, the mean density was significantly different among the three habitats or between the two areas.

Table 1 Korean water deer densities in different habitats and elevations

Study sites	Elevation (m)	Sample size (n)	Total area (km^2)	Density range (min–max)	Mean density (ind./km^2)	Standard deviation
Lowland areas	<300	101	29.151	0.35–24.13	6.93	7.94
Mountainous areas	>300	60	32.815	0.36–5.25	1.91	1.53
Urban areas	–	9	20.829	0.08–2.38	1.27	0.95

Table 2 Slope preference and avoidance of the Korean water deer based on fecal deposits in Cheorwon County (significant difference between observed and expected slope types, Chi-square test, $P < 0.01$)

Slope (°)	No. of pixels	Expected proportion	Expected frequency	Observed frequency	Bonferroni confidence interval significant difference
0–5	517	0.36	17	11	
5–10	271	0.19	9	8	
10–15	288	0.2	9	8	
15–20	206	0.14	7	7	
20–25	103	0.07	3	11	*
≥25	40	0.03	1	2	
Total	1,425	1	47	47	

Average slope of survey route 12.6 ± 8.7°, slope range 0°–35.5°

* Proportion greater than its availability ($P < 0.01$)

Table 3 Habitat preference and avoidance of the Korean water deer based on fecal deposits in Cheorwon County (Chi-square test, $P < 0.01$)

Habitat types	No. of pixels	Expected proportion	Expected frequency	Observed frequency	Bonferroni confidence interval significant difference
Residential area	40	0.03	1.3	0	
Paddy field	168	0.12	5.47	3	
Agricultural area	156	0.11	5.08	5	
Broadleaf forest	209	0.14	6.81	17	*
Coniferous forest	464	0.32	15.11	11	
Mixed forest	244	0.17	7.95	6	
Grassland	107	0.07	3.49	5	
Bare land	55	0.04	1.79	0	
Total	1,443	1	47	47	

The broadleaf forest was the most preferred habitat

* Proportion that was greater than its availability ($P < 0.01$)

Habitat use

Overall, habitat slope ranged from 0° to 88.1° and averaged 20.1 ± 13.2°. Study sites were 43.3% broadleaf forest, 20.83% coniferous forest, 12.0% paddy field, 11.8% mixed forest. Deer tended to prefer a slope of 20°–24.99° but did not avoid any slope (slope, Chi-square test, $P < 0.01$; Table 2). BCI analysis also showed that the Korean water deer tended to prefer broadleaf forest but also used other habitat types (habitat type, Chi-square test, $P < 0.01$; Table 3).

Discussion

Our detailed analyses yielded patterns of water deer distribution based on location, water availability, and human population size. Korean water deer seem to occur in most areas of South Korea except for Seoul and Jeju Province (Fig. 1). Deer occurred in but tended to avoid Kyunggi Province, which is near Seoul and one of the most actively developed areas. Other Korean mammals may show similar distribution patterns in such urbanized locations. Second, water availability is presumably very important for deer, as they were more often found in inland areas than coastal areas (Fig. 2). Wild mammals generally require a supply of fresh water around their habitats. In particular, water deer prefer areas with wetlands or streams (Zhang et al. 2006). Whereas Chinese water deer have been reported to prefer areas that are 200–599 m away from water sources (Zhang et al. 2006), Korean water deer prefer habitat within 1.6 km of water. Finally, we found that even though deer are relatively well adapted to the Korean peninsula, high human population size reduced their occurrence (Fig. 2). Water deer and other Korean ungulate species (or subspecies) also suffer from the risks of anthropogenic disturbances, such as roadkill, lack of habitat, habitat fragmentation, and so on, especially in or near large cities.

Although there was no significant difference in mean density among the three habitat types, water deer were most dense in lowland areas, followed by mountainous and then urban areas (Table 1). Lowland areas might provide deer with better cover and food, both of which are essential for survival (B. J. Kim, personal observation). This observation is supported by data from other locations. In China, for instance, deer typically inhabit river shores or coastal areas

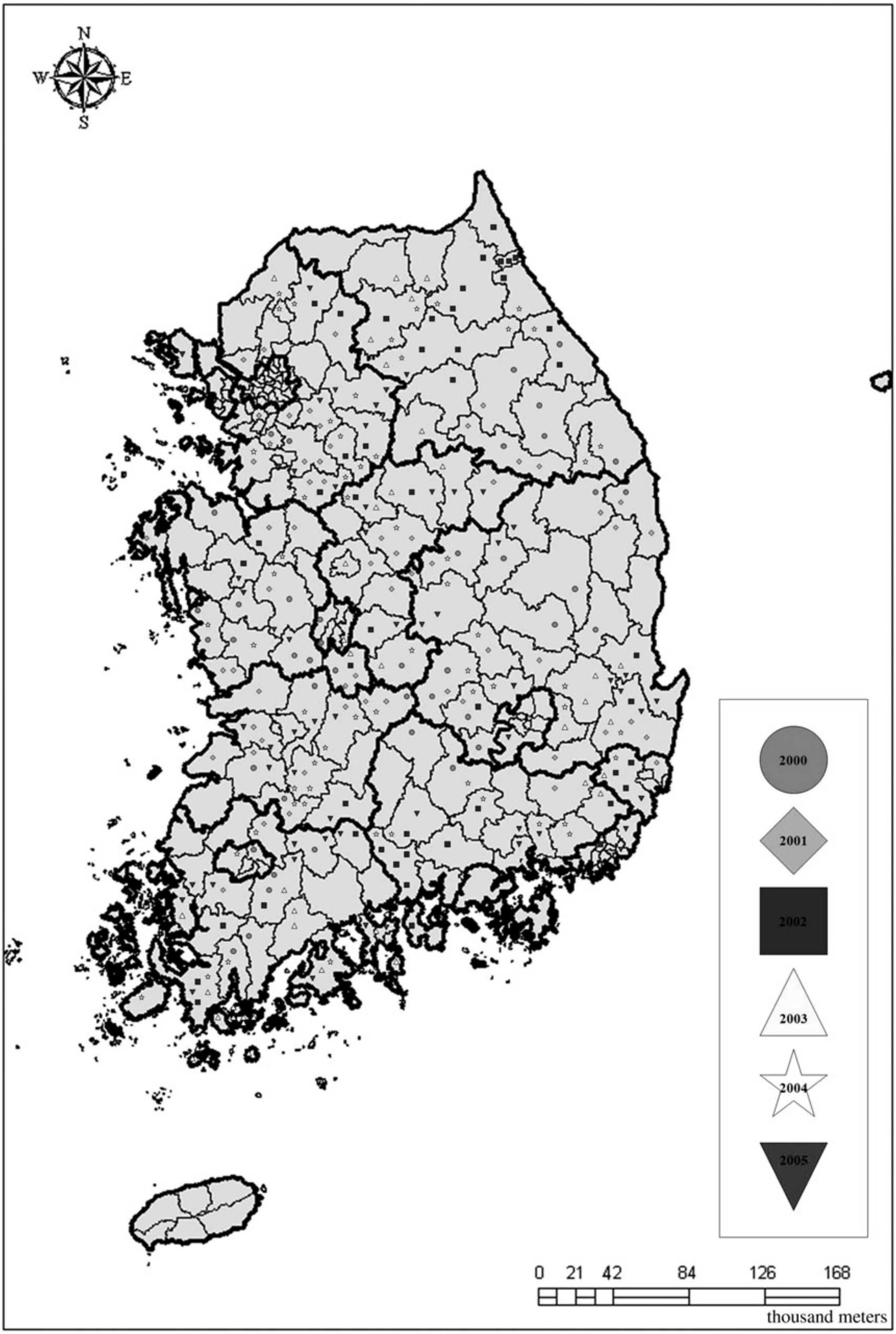

Fig. 1 Distribution map of the Korean water deer based on data from the Korean Ministry of Environment (2000–2005 National Survey of Natural Environment)

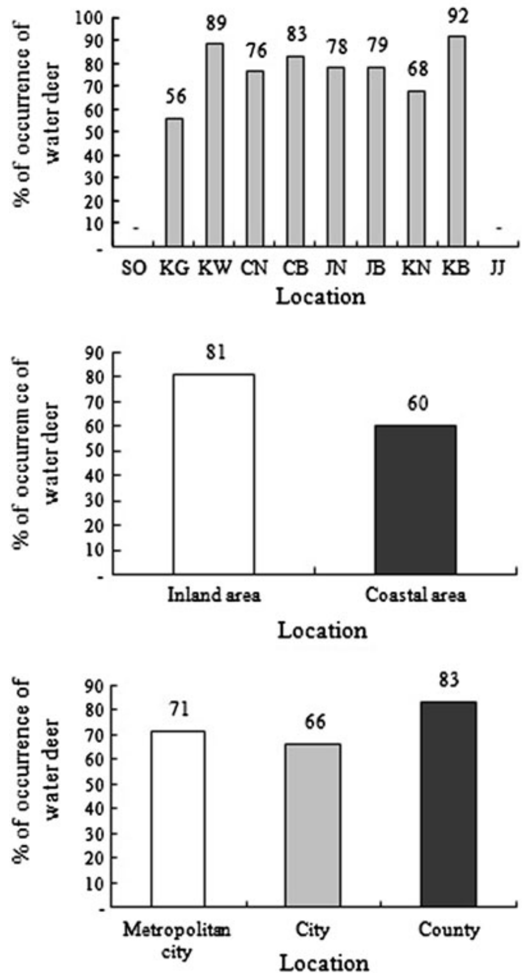

Fig. 2 Patterns of Korean water deer distribution based on location (*top*), water availability (*middle*), and human population size (*bottom*). Areas are abbreviated as follows: *SO* Seoul metropolitan city, *KG* Kyunggi, *KW* Kangwon, *CN* Chungnam, *CB* Chungbuk, *JN* Jeonam, *JB* Jeonbuk, *KN* Kyungnam, *KB* Kyungbuk Province, *JJ* Jeju Island. *Metropolitan city* and *city* indicate large cities, and *county* indicates rural areas

with reeds and other tall grasses, hilly grasslands, and along lakes in lowland areas (Cooke and Farrell 1998). Such habitats provide ample cover (e.g., reeds and other tall grasses) and food (e.g., sedges) (Cooke and Farrell 1998). In England, deer also occur in grasslands, arable land, reeds, scrub, and woodlands in lowland areas (Cooke and Farrell 1998). In addition, although there was no significant difference in mean density between the two elevations, deer were much denser at low elevations (<300 m) than at high elevations (>300 m). Yang (2002) also reported that Korean water deer were usually observed at low elevations (<600 m). Based on the results of this and other studies, then, lowland areas with low elevation are likely the most suitable habitats.

Based on our observations deer home range on a small island, they usually rest and feed in lowland areas with low elevation during the day but move to feed in mountainous areas with high elevation during the night (Kim et al., in preparation). In this study, the lack of significant differences in mean deer density among the three habitat types or between the two elevations may have been due to our limited sample size over a wide range of study sites. At the level of $\alpha = 0.10$, a significant difference was found for both habitat types and elevations. In addition, our new long-term study, for which we used the same density estimation method, showed significant differences for the same parameters (B. J. Kim, unpublished data). The major difference between this study and that ongoing is that in the ongoing study, we used a large sample size of feces from one target study site (a small island) rather than a relatively small number of fecal deposits across many different study sites.

Finally, whereas water deer in Cheorwon preferred 20°–24.99° slopes and broadleaf forest for defecation (Table 2), the results of this study suggest that they might be adapted to most slopes and habitat types. In general, wild deer prefer slopes close to 0°, but there are few places with such slopes in mountainous areas, and carnivores [e.g., leopard cats (*Prionailurus bengalensis*), martens (*Martes flavigula*), weasels (*Mustela sibirica*), badgers (*Meles meles*), and raccoon dogs (*Nyctereutes procyonoides*)] tend to use flat habitats in mountains (D. H. Oh, personal observation). In this study, only a few water deer fecal deposits ($n = 11$ of 47 points) were found on such flat slopes, presumably, because deer are trying to avoid being attacked by carnivores. In addition, deer appeared to select southward-facing slanted areas to rest or keep themselves warm during the day (D. H. Oh, personal observation). On the other hand, deer frequently used broadleaf forest for defecation due to its suitability for resting and/or food plants, which are much more abundant than in other habitat types. During the field survey, we sometimes observed that deer fed on leaves of shrubs or arbors [e.g., black locust (*Robinia pseudoacacia*), willow (*Salix koreensis*)] and more frequently fed on herbs on the ground under the trees (B. J. Kim, personal observation).

This study was intended to present a general picture of the distribution, density, and habitat use of the Korean water deer. Whereas the fundamental information gained in these three areas is very useful, both quantitative distribution data and more extensive density and habitat use data are needed for future ecological studies. In addition, whereas this study did not address human–wildlife conflict, the issue of water deer conflict with local farmers is critically important for population management and conservation and should be thoroughly addressed.

Acknowledgments The authors thank ERC (2009-1419-1-6) and SWRRC (1-0-3), and Dr. R. Morrison for providing with critical review on this study.

References

Borkowski J (2004) Distribution and habitat use by red and roe deer following a large forest fire in South-western Poland. For Ecol Manag 201:287–293

Butzler W (1990) Grzimek's encyclopedia mammals, volume 5. McGraw-Hill, New York

Byers CR, Steinhorst RK (1984) Clarification of a technique for analysis of utilization-availability data. J Wildl Manag 48: 1050–1053

Collins WB, Urness PJ (1981) Habitat preferences of mule deer as rated by pellet-group distribution. J Wildl Manag 45:969–972

Cooke A, Farrell L (1998) Chinese water deer. The Mammal Society and the British Deer Society, London

Dobiáš K, Paustian KH, Tottewitz F (1996) Untersuchungen zur Bestandeshöhe und Dynamik der Schalenwildpopulationen in der Schorfheide. Beiträge zur jagd - und Wildforschung 21:57–62

Geist V (1998) Deer of the world: their evolution, behaviour, and ecology. Stackpole Books, Mechanicsburg

Guillet C, Bergstrom R, Cederlund G, Bergstrom J, Ballon P (1995) Comparison of telemetry and pellet-group counts for determining habitat selectivity by roe deer in winter. Gibier Faune Sauvage 12:253–269

Harris RB, Duckworth JW (2008) Hydropotes inermis. In: IUCN 2010. IUCN Red List of Threatened Species Version 2010.1

Hu J, Fang SG, Wan QH (2006) Genetic diversity of Chinese water deer (*Hydropotes inermis inermis*): implication for conservation. Biochem Genet 44:161–172

Hu J, Pan HJ, Wan QH, Fang SG (2007) Neuclear DNA microsatellite analysis of genetic diversity in captive populations of Chinese water deer. Small Rumin Res 67:252–256

Kiyota M, Okamura H, Yonezaki S, Hiramatsu K (2005) A review of statistical analyses on resource selection—2. Introduction to several analysis techniques. Honyurui Kagaku. Mammalian Sci 45:1–24 (in Japanese)

Lee BK (2003) Morphological, ecological and DNA taxonomic characteristics of Chinese water deer (*Hydropotes inermis* Swinhoe). PhD thesis, Cheongju, Chungbuk National University, Rep. Korea (in Korean)

Marques FFC, Buckland ST, Goffin D, Dixon CE, Borchers DL, Mayle BA, Peace AJ (2001) Estimating deer abundance form line transect surveys of dung: sika deer in southern Scotland. J Appl Ecol 38:349–363

Ministry of Construction and Transportation (2007) 2007 Annual statistics report of ministry of construction and transportation, Korea (in Korea)

Ministry of Environment of Korea (2000–2005) 2000–2005 Report of the nature environment investigation. National Institute of Environmental Research, Korea (in Korean)

Neu CW, Byers CR, Peek JM (1974) A technique for analysis of utilization-availability data. J Wildl Manag 38:541–545

Wang S (1998) China red data book of endangered animals (mammal volume). Science Press, Beijing (in Chinese)

Welch D, Staines BW, Catt DC, Scott D (1990) Habitat usage by red (*Cervus elaphus*) and roe (*Capreolus capreolus*) deer in a Scottish Sitka spruce plantation. J Zool 221:453–476

White GC, Garrot RA (1990) Habitat analysis. In: Analysis of wildlife radio-tracking data. Academic Press, San Diego, pp 183–205

Won PH (1967) Illustrated encyclopedia of fauna and flora of Korea, Mammals, vol 7. Ministry of Education, Seoul in Korean

Won CM, Smith KG (1999) History and current status of mammals of the Korean peninsula. Mammal Rev 29(1):3–36

Woo HC, Lee JI, Son SW, Park HS (1990) Ecological survey of mammals in South Korea (IV). Ministry of Environment, Seoul (in Korean)

Xu HF, Zheng XZ, Lu HJ (1999) Impact of human activities and habitat changes on distribution of Chinese water deer along the coast area in Northern Jiangsu. Acta Theriologica Sinica 18:161–167 (in Chinese)

Yang BG (2002) Systematics, ecology and current population status of the goral, *Naehorhedus caudatus*, in Korea. PhD thesis, Cheongju, Chungbuk National University, Republic of Korea

Zhang E, Teng L, Wu Y (2006) Habitat selection of the Chinese water deer (*Hydropotes inermis*) in Yancheng Reserve, Jiangsu Province. Acta Theriologica Sinica 26:49–53 (in Chinese)

Zhu H, Qin P, Wang H (2004) Functional group classification and target species selection for Yancheng Nature Reserve, China. Biodivers Conserv 13:1335–1353