

Influence of Topography on the Summer Habitat Use by the Korean Water Deer *Hydropotes inermis argyropus* Heude, 1884 (Artiodactyla: Cervidae) in a Low-mountainous Area

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Abstract: Resource availability is a key factor affecting habitat use by animals across all habitat selection scales, from species distribution to individual behaviour. As vegetation structure and composition vary with different terrain features, topography is expected to influence the distribution of resources used by animals. We, therefore, tested topographical differences in resource availability and habitat use by animals, using the Korean water deer *Hydropotes inermis argyropus* Heude, 1884 as our study subject. We surveyed deer field signs and built habitat use models using each of three topographic features ridge, slope and valley. The models were based on variables related to vegetation cover in the understory, mid-story and overstory and to food availability (forbs, shrubs and graminoids). The availability of both food and cover differed with topography; the habitat use pattern of the Korean water deer reflected this topographical variance in resource distribution. The faecal sign frequency was the highest on the ridges, where the deer prioritised sites with more understory cover over food, using them for resting. Most feeding activity occurred in the valley, where the deer selected sites containing abundant food, prioritising this over understory cover. On the slope, deer selected sites with more canopy cover. The results showed that topography had a significant influence on habitat selection by the deer, mediated by resource distribution.

Key words: Abundance, cover, Cervidae, field sign, food, Korean Peninsula

Introduction

Resource allocation, including time, space and energy, is essential for wildlife survival strategies (ZHANG 2000). In particular, habitat use is the optimal way in which resource allocation can be exploited (LEE et al. 2017). Spatial and temporal variations in habitat use are the result of changes in the quantity and quality of resources (WIENS 1989, HIRZEL & LE LAY 2008). Spatial variances in habitat use have indeed long been recognised as a functional theme in wildlife ecology (MANCINELLI et al. 2015).

Topography is one of the main factors underlying spatial heterogeneity in habitat structure. Numerous studies have demonstrated how topography affects habitat selection by wildlife at landscape and regional scales (MYSTERUD 1999, POMPILIO &

MERIGGI 2001, LONE et al. 2014). However, its influence on habitat use by animals is not clearly understood, although the impacts of topography on vegetation, an important habitat factor for animals, is recognised (ALEXANDER et al. 2016). Topography causes variations in vegetation structure and composition by altering the influence of solar energy, wind exposure, hydrology and geochemistry (MOESLUND et al. 2013). Therefore, we expected that topography would affect the distribution of vegetative resources used by animals.

Topographical differences in resource availability, such as the quality and quantity of food, availability of sustainable cover for shelter and resting and water availability influence habitat use and

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selection by animals (GODVIK et al. 2009, HWANG et al. 2014, PARK et al. 2014). If resource distribution follows a topographical pattern, then this should be reflected in habitat use by wildlife. Thus, comparing resource selection among topographies can help in understanding animal survival strategies. In the context of habitat management, it also provides insight into how topographical differences in habitat structure should be managed.

The Korean water deer *Hydropotes inermis argyropus* Heude, 1884 an endemic subspecies of the Korean Peninsula, is abundant in low mountainous and riparian areas (WON & SMITH 1999, KIM & LEE 2011). Deer-facilitated crop damage and vehicle-wildlife conflict (including roadkill) have become severe problems in South Korea (JUNG et al. 2011, LEE et al. 2017). However, despite its high population density in South Korea, few studies have been undertaken on the Korean water deer. If the deer are to be managed effectively on the Korean Peninsula, it is essential to understand how they use habitats and, in particular, how this is influenced by topography. The low mountainous habitats inhabited by most Korean water deer have highly rugged terrains. This heterogeneity could result in topographical variances in resource availability. Thus, we expected that topography would affect habitat use by the deer.

We, therefore, studied habitat selection by the Korean water deer in different terrains, characterised by differences in vegetation cover and food availability, in a low mountainous area. We hypothesised that: 1) resource distribution, i.e. cover and forage resources, would vary with topography and 2) the habitat selection strategy of the Korean water deer would differ among topographies according to resource availability.

Materials and Methods

The present study was conducted from May to September 2016 in the low mountainous area of Maehwa Mt., Hongcheon, South Korea (N37 40, E127 52). The annual precipitation in the region is 828 mm, the annual mean temperature is 10.8°C (range: 35.7 to -19.6°C) and the altitude ranges from 250 to 450 m a.s.l. The dominant tree species are the Chinese cork oak *Quercus variabilis* (Blume, 1851), Mongolian oak *Q. mongolica* (Fisch, 1850), Korean red pine *Pinus densiflora* (Siebold & Zucc, 1842), Korean pine *P. koraiensis* (Siebold & Zucc., 1842) and the Japanese larch *Larix kaempferi* (Carrière, 1856) (KOREA FOREST SERVICE 2012). We selected the study area based on the presence of the following topographic features: a ridge (a continuous elevated

crest), slope (a surface that rises at an angle to the horizontal) and valley (a relatively low area between mountains, usually with streams). Three transects (1 km long and 4 m wide) were selected in each topography (i.e. nine in total in the study area), spatially separated from each other by a distance of 500 m.

In August 2016, we established 40 circular plots (diameter = 5 m) at 25 m intervals along each transect (RHIM et al. 2015), corresponding to the square plots mentioned above. These circular plots were used to measure habitat variables describing vegetation cover and available food resources (Table 1). We measured vertical vegetation cover in each circular plot to represent cover resources available for the Korean water deer. Five categories of vertical vegetation cover were delineated within each circular plot: v0 (0–1 m), v1 (1–2 m), v2 (2–8 m), v8 (8–20 m) and v20 (20–30 m). Vegetation coverage was measured based on the percentage of foliage cover: 0 (percentage coverage = 0%), 1 (1%–33%), 2 (34%–66%) and 3 (67%–100%) (SON et al. 2017). As forbs, shrubs and graminoids are known to be major forage resources used by the Korean water deer (KIM et al. 2011), we measured their coverage (%) within each circular plot from ground level to 2 m height (RHIM 2013, HWANG et al. 2014). We did not measure the distance of transects from water sources in the study area. Most transects were within 200 m of a water source: there were many small streams in the valleys in the study area in summer. Therefore, the Korean water deer that were using ridge and slope locations would still have good access to water and we assumed that the distance from water sources did not influence habitat use.

We recorded total field signs, including faecal and feeding signs, of the Korean water deer once per month during the study period. We conducted three tracking sessions along each of the nine transects. Only fresh field signs were counted during the present study. In order to avoid duplication, we recorded GPS coordinates and took photographs of each field sign. In the case of faecal pellet groups, we removed them from transects after each survey. Moreover, only fresh pellet groups containing four or more pellets were counted. When recording feeding signs, a plant exhibiting one or more feeding signs was counted as a single unit.

Faecal pellet counts have previously been used by ecologists to study habitat use by animals such as deer and rabbits (Månsson et al. 2011). Deer defecate randomly rather than accumulatively, so their faecal signs should increase proportionally with increasing time for which deer are present in a locality. Therefore, we used the number of faecal

Table 1. Description of cover and forage variables.

Variable		Description
Cover	v0	Coverage* (0, 1, 2, 3) of vegetation from ground to 1 m
	v1	Coverage (0, 1, 2, 3) of vegetation from 1 to 2 m
	v2	Coverage (0, 1, 2, 3) of vegetation from 2 to 8 m
	v8	Coverage (0, 1, 2, 3) of vegetation from 8 to 20 m
	v20	Coverage (0, 1, 2, 3) of vegetation from 20 to 30 m
Forage	forb	Coverage (%) of forb from ground to 2 m
	shrub	Coverage (%) of shrub and sapling from ground to 2 m
	graminoid	Coverage (%) of graminoid from ground to 2 m

*In each vertical cover layer, coverage was measured based on the percentage of foliage cover: 0 (percentage coverage = 0%), 1 (1%–33%), 2 (34%–66%) and 3 (67%–100%) (SON et al. 2017)

Table 2. Rotated component matrix for the vertical vegetation structure variables.

	FAC1*	FAC2*	FAC3*
Variance	27.50%	25.23%	21.29%
v0	0.79	-0.05	-0.27
v1	0.71	0.36	-0.25
v2	0.25	0.27	0.85
v8	-0.42	0.61	-0.44
v20	-0.03	0.83	0.14

*FAC1, FAC2 and FAC3 are the three cover variables reduced from the original five (v0, v1, v2, v8 and v20) with principal component analysis, in order to prevent multicollinearities among the variables.

signs recorded per tracking day in each square plot as a habitat use index (no. of field signs per 100 m; RHIM & LEE 2007, HWANG et al. 2014, EOM 2017). We also calculated the frequency of feeding signs in order to compare deer feeding activities among the topographies.

The mean values of habitat variables and field sign frequency among the topographies were compared using Kruskal–Wallis tests. In order to avoid multicollinearity, we used principal component analysis (PCA) to reduce the number of cover variables from five (v0, v1, v2, v8 and v20) to three (FAC1, FAC2, FAC3) before model analysis. Vegetation coverage values from ground to 1 m height and from 1 to 2 m in FAC1, from 8 to 20 m and over 20 m in FAC2 and from 2 to 8 m in FAC3 were determinative (Table 2). Thus, we assumed that the determinative vegetation layers were represented by FAC1 (understory), FAC2 (overstory) and FAC3 (midstory).

We used Generalized Linear Models (GLMs) with a Poisson distribution to evaluate habitat selection by Korean water deer (EOM 2017). We built habitat selection models for each topography, each

of which included three cover variables (FAC1, FAC2 and FAC3) and three food variables (forbs, shrubs and graminoids). The total number of field signs in each square plot was the dependent variable of the models. Then, we ranked the models for each topography using the corrected Akaike information criterion (AIC_c). In order to examine multicollinearities among variables in the first models, we examined whether or not variance inflation factors (VIF) of variables in the habitat use models had values > 3 (ZUUR et al. 2010). We used the SPSS statistical package version 23.0 to perform the Kruskal–Wallis tests and PCA and the MuMIn package in R version 3.4.1 for the model analysis and evaluation (MANCINELLI et al. 2015).

Results

The mean values of all cover and food resource variables differed significantly among the ridge, slope and valley (Kruskal–Wallis test, $\chi^2 > 12.09$, $p < 0.01$). In terms of cover availability, understory cover (i.e. cover resource under 2 m height), was more abundant on the ridge and valley as compared with the slope. Additionally, the vertical distribution of canopy cover (over 2 m height) varied among topographies. The densest of all canopy layers was found on the slopes. Food availability also varied with topography. The valley contained abundant forbs and shrubs, the ridge contained plentiful shrubs and graminoids, whereas the slope had poor food availability (Table 3).

In order to determine how habitat selection of Korean water deer depended on topography, we measured frequency of faecal and feeding signs as a relative habitat use and feeding activity index, respectively. The faecal sign ($\chi^2 = 140.15$, $p < 0.001$) and feeding sign ($\chi^2 = 87.10$, $p < 0.001$) frequencies of the

Table 3. Differences in cover and forage variables (mean \pm SE) among topographies in a low mountainous area, Mt. Maehwa, Hongcheon, South Korea estimated using a Kruskal–Wallis test.

Variable		Topography			χ^2	p
		Ridge	Slope	Valley		
Cover	v0	1.78 \pm 0.71 ^a	1.17 \pm 1.00 ^b	1.86 \pm 0.96 ^a	36.85	<0.001
	v1	1.27 \pm 0.70 ^a	0.97 \pm 0.81 ^b	1.32 \pm 0.96 ^a	12.09	<0.01
	v2	1.42 \pm 1.03 ^b	2.14 \pm 0.87 ^a	2.32 \pm 1.05 ^a	52.99	<0.001
	v8	1.67 \pm 1.11 ^a	1.75 \pm 1.06 ^a	1.01 \pm 1.05 ^b	31.65	<0.001
	v20	0.00 \pm 0.00 ^b	0.63 \pm 0.93 ^a	0.43 \pm 0.68 ^a	58.65	<0.001
Food	forb	4.07 \pm 9.90 ^b	7.77 \pm 13.08 ^b	20.34 \pm 25.04 ^a	38.66	<0.001
	shrub	24.12 \pm 18.89 ^a	11.40 \pm 16.03 ^b	24.09 \pm 31.45 ^a	34.95	<0.001
	graminoid	19.96 \pm 17.65 ^a	9.24 \pm 14.87 ^b	4.50 \pm 10.46 ^c	95.13	<0.001

Rows with different superscript letters indicate significant differences. Cover variables represent vertical layers of vegetation coverage: v0 (0–1 m), v1 (1–2 m), v2 (2–8 m), v8 (8–20 m) and v20 (20–30 m). Forage variables represent food item coverage from ground to 2 m (see Table 1).

Table 4. Differences in observed fecal and feeding signs (no./100 m, mean \pm SE) of Korean water deer *Hydropotes inermis argyropus* among topographies in a low mountainous area, Mt. Maehwa, Hongcheon, South Korea estimated using a Kruskal–Wallis test.

Field sign	Topography			χ^2	p
	Ridge	Slope	Valley		
Feces	3.94 \pm 6.65 ^a	0.36 \pm 1.51 ^c	2.37 \pm 6.43 ^b	140.15	<0.001
Feeding	0.19 \pm 1.08 ^c	0.96 \pm 4.04 ^b	6.14 \pm 20.18 ^a	87.10	<0.001

Rows with different superscript letters indicate significant differences.

deer were significantly different among the topographies. Faecal frequency was the highest on the ridge and yielded high values in the valley but was relatively low on the slope. The distribution of feeding signs was highly concentrated in the valley, whereas feeding behaviour occurred rather infrequently on the ridge and slope (Table 4).

We modelled habitat selection of Korean water deer in each of the topographies, based on cover resources (in the understory, midstory and overstory) and on food resources obtained from forbs, shrubs and graminoids. The models revealed that habitat selection by the deer was dependent on topography. The top three models in each topography, with an ΔAIC_c value of <2, are shown in Table 5.

On the ridge, the best models for habitat selection by Korean water deer had an Akaike weight (ω) of 0.18–0.41. The models were constructed as follows: first model $0.52 + 0.49 \times FAC1 - 0.22 \times FAC2 - 0.01 \times forb - 0.01 \times shrub - 0.01 \times graminoid$ (χ^2 -test, deviance=–39.96, p <0.001); second model FAC1, FAC2, FAC3, forb, shrub and graminoid and third model FAC1, FAC2, FAC3, shrub and graminoid. The ridge models indicated that the deer tended to use sites with an abundant understory and poor overstory.

On the slope, first model was $-1.31 + 0.25 \times FAC1 + 0.19 \times FAC2 + 0.10 \times FAC3$ (deviance=–11.22, p =0.01). Cover resource in the understory (FAC1) and overstory (FAC2) were the two dominant predictor variables in the second-ranked model for habitat selection. The third model contained FAC1, FAC2, FAC3 and graminoid.

In the valley, the best models had an Akaike weight (ω) of 0.31–0.69. The first model was $0.05 + 0.22 \times FAC1 + 0.19 \times FAC3 + 0.01 \times forb + 0.02 \times shrub + 0.03 \times graminoid$ (deviance=–78.02, p <0.001). Moreover, the second model contained FAC1, FAC2, FAC3, forb, shrub and graminoid (Tables 5 and 6).

In the ridge and valley habitat-selection models, the food variables coefficients did not explain the impact of food availability on habitat selection by the deer. However, there were constantly positive tendency of forb, shrub and graminoid variables in the valley model and negative tendency of three food variables in the ridge model. Additionally, the p-values of variables in the ridge and the valley models were highly significant. Thus, we interpreted this as indicating that the influence of food availability on habitat selection by the deer was positive on the ridge and negative in the valley.

Table 5. Models based on the corrected Akaike information criterion (AIC_c) built to explain the observed field signs for Korean water deer *Hydropotes inermis argyropus* in each of three topographies ranked by the ΔAIC_c value derived from a Generalized Linear Model with Poisson distribution.

Topography	Model	AIC_c	ΔAIC_c	ω	R^2
Ridge	[intercept + FAC1 + FAC2 + forb + shrub + graminoid]	1274.02	0.00	0.41	0.14
	[intercept + FAC1 + FAC2 + FAC3 + forb + shrub + graminoid]	1274.03	0.01	0.41	0.15
	[intercept + FAC1 + FAC2 + FAC3 + shrub + graminoid]	1275.64	1.62	0.18	0.14
Slope	[intercept + FAC1 + FAC2 + FAC3]	654.22	0.00	0.11	0.05
	[intercept + FAC1 + FAC2]	654.25	0.04	0.11	0.04
	[intercept + FAC1 + FAC2 + FAC3 + graminoid]	654.37	0.15	0.10	0.05
Valley	[intercept + FAC1 + FAC3 + forb + shrub + graminoid]	2344.61	0.00	0.69	0.40
	[intercept + FAC1 + FAC2 + FAC3 + forb + shrub + graminoid]	2346.18	1.57	0.31	0.40

The table exhibits the top three models for the ridge and valley topographies with an ΔAIC_c value <2 . The valley topography only yields two models with $\Delta AIC_c < 2$. FAC1, FAC2 and FAC3 were derived with principal component analysis (PCA) from vertical layers of vegetation. FAC1 represents cover resources in the understory (ground level to 2 m height), FAC2 represents cover in the overstory (over 8 m height) and FAC3 represents cover in the mid-story (2 m to 8 m height). Forb, shrub and graminoid represent food resources from ground level to 2 m height.

Table 6. Coefficients of the first Generalized Linear Models with Poisson distributions for summer habitat selection by Korean water deer *Hydropotes inermis argyropus* depending on topography.

Model	Variable	Coefficient	SE	Z	p
Ridge	Intercept	0.52	0.11	4.84	<0.001
	FAC1	0.49	0.09	5.51	<0.001
	FAC2	-0.22	0.05	-4.79	<0.001
	FAC3				
	forb	-0.01	0.01	-2.13	0.03
	shrub	-0.01	0.00	-3.71	<0.001
	graminoid	-0.01	0.00	-4.61	<0.001
Slope	Intercept	-1.31	0.13	-9.93	<0.001
	FAC1	-0.25	0.10	-2.61	<0.01
	FAC2	0.19	0.11	1.79	0.07
	FAC3	0.10	0.07	1.47	0.14
	forb				
	shrub				
	graminoid				
Valley	Intercept	0.05	0.08	0.55	0.58
	FAC1	-0.22	0.05	-4.28	<0.001
	FAC2				
	FAC3	0.19	0.03	7.05	<0.001
	forb	0.01	0.00	6.43	<0.001
	shrub	0.02	0.00	9.31	<0.001
	graminoid	0.03	0.00	9.59	<0.001

Discussion

In terms of habitat use, animals usually prefer to select different habitat structures to meet the requirements of different behaviours such as feeding or refuge. In our study, topography created a spatial variance in vegetation structure that was highly related to the distribution of resources available to the deer, such as food and cover. The deer were observed to adjust their habitat use and behaviour according to this topographical distribution of food and cover resources.

Faecal sign frequency was the highest on the ridge, while feeding sign frequency was the lowest in this topography. Cervids spend most of their time in resting and feeding (KIE et al. 1991). In summer, water deer feed and rest for 59% and 40% of the day, respectively (ZHANG 2000). Therefore, we deduced that the Korean water deer in our study were engaging in resting behaviour for most of their time spent on the ridge. Furthermore, the deer favoured sites on the ridge with more understory cover, rather than selecting sites for food and overstory cover. Sufficient understory cover is essential for finding suitable resting sites that provide refuges from predators (MYSTERUD & OSTBYE 1999, BOLEN & ROBINSON 2003). At our study site, understory cover was more abundant on the ridge than on the slope but was also abundant in the valley. However, Korean water deer mostly used the ridge rather than valley for resting. On the ridge, the amount of flies and mosquitos is usually low, due to the more prominent wind. This is also the reason for choosing rest sites with less

overstory, which serves as a more effective barrier for these insects. Topography is again the probable explanation for this, by directly influencing behaviour related to movement, predator avoidance and rest (MYSTERUD & OSTBYE 1999, DICKSON & BEIER 2007). Topographical features affect the hunting success of predators and flight tactics of their prey, creating a topography-dependent landscape of fear (LONE et al. 2014). At our study site, the wide views from the ridge allowed the deer to detect predators at greater distances, thus enabling them to escape predation more easily (LINGLE 2002) and explaining why the ridge was preferred as a resting site, despite both ridge and valley having abundant understory cover. RATIKAINEN et al. (2007) report that roe deer *Capreolus capreolus* (Linnaeus, 1758) use elevated locations as resting sites in habitats where predators are present. Similarly, FARMER et al. (2006) state that topography, especially flat terrain, potentially heightens the risk of predation and consequent mortality of Sitka black-tailed deer *Odocoileus hemionus sitkensis* (Richardson, 1892).

Vegetation usually has dual roles for resting deer: it provides climate and predatory cover (MYSTERUD & OSTBYE 1999). Climate cover protects the deer against adverse weather conditions, such as radiation, rain and wind; deer often use vegetation canopy as a climate cover (RATIKAINEN et al. 2007). Canopy cover was most abundant on the slope. The Korean water deer selected sites with more cover in the midstory and overstory rather than understory layers. This could be due to requirements for thermoregulation, with canopy cover used to avoid hot radiation in the summer. Similarly, roe deer have been reported to prefer dense canopy cover in order to avoid hot sunlight in summer (MYSTERUD 1996, MANCINELLI et al. 2015).

The feeding activity of Korean water deer appeared to be affected by topographical variances in food availability. In this study, most feeding signs (84%) were observed in the valley, where forb, a high-quality food item, was abundant. Forbs are known to be an important summer food resource for Korean water deer (KIM et al. 2011). Furthermore, the nutritional quality of plants for herbivores usually depends on soil fertility. In hydrological processes, soil minerals are concentrated by the ridge to valley water flow, meaning valleys have a higher soil fertility (LIKENS & BORMANN 1999). In our study, Korean water deer responded to the distribution of high-quality food by preferring the valley site, which contained more food resources. This result contrasted with the habitat selection in the other topographies. On the ridge and slope, there was a

lack of feeding signs, with the deer preferring sites with more cover rather than food. Therefore, we assumed the valley to be the main deer feeding site during summer, owing to the availability of plentiful food. Water availability in the valley could also affect habitat selection by Korean water deer because streams or wetlands are essential to their survival (YOU 2000, KIM et al. 2011).

Trade-off is a well-known habitat use strategy employed by cervids, in which deer select one resource over another in accordance with the immediate purpose of the behaviour, because they cannot satisfy all needs in one location. The representative trade-off is that deer usually select food rather than cover at feeding sites (MYSTERUD et al. 1999). A trade-off can also vary according to factors determining resource distribution, such as landscape structure and season (GODVIK et al. 2009). In our study, we observed that trade-off patterns differed depending on topography. Water deer behaviour, especially feeding and resting, reflected topographical differences in resource availability. Thus, the highest priority resource for the Korean water deer altered with topography: when feeding in the valley, they prioritised food resource rather than cover and when resting on the ridge, they prioritised cover over finding food.

Furthermore, there was a seasonal variation in trade-offs in the study area. In a previous study, we had carried out an experiment with the same design as the current study but in winter (EOM 2017), with the earlier study yielding quite different results. We did not observe a topography-dependent trade-offs in winter and Korean water deer exhibited similar feeding activities and selected sites with more abundant food in all topographies. These contrasting results between summer and winter studies are probably caused by seasonal changes in food availability. In winter, the deer have to search for food in all topographies to satisfy their nutritional requirements because of the dramatic decrease in the availability of high-quality food, such as forbs.

In conclusion, our study determined that topography highly influenced habitat use by the Korean water deer in a low mountainous area during summer. The topographical influence on habitat use by animals may vary in different landscape structures. An understanding of the topographical influence on habitat selection in various landscapes will, therefore, be helpful in improving our understanding of habitat use of animals in highly heterogeneous habitats. Further study of the topographical influence on habitat use by Korean water deer is required across various habitat types on the Korean Peninsula, in order to support improved management of the deer and their habitat.

References

- ALEXANDER C., DEÁK B. & HEILMEIER H. 2016. Micro-topography driven vegetation patterns in open mosaic landscapes. *Ecological Indicators* 60: 906–920.
- BOLEN E. G. & ROBINSON W. L. 2003. *Wildlife ecology and management*. Fifth edition. Pearson Education Inc. Upper Saddle River, USA. 634 p.
- DICKSON B. G. & BEIER P. 2007. Quantifying the influence of topographic position on cougar (*Puma concolor*) movement in southern California, USA. *Journal of Zoology* 271: 270–277.
- EOM T. K. 2017. Influence of topography and season on habitat use of Korean water deer (*Hydropotes inermis argyropus*). MSc thesis, Chung-Ang University. Seoul, Korea. 52 p.
- FARMER C. J., PERSON D. K. & BOWYER R. T. 2006. Risk factors and mortality of black-tailed deer in a managed forest landscape. *Journal of Wildlife Management* 70: 1403–1415.
- GODVIK I. M. R., LOE L. E., VIK J. O., VEIBERG V., LANGVATN R. & MYSTERUD A. 2009. Temporal scales, trade-offs, and functional responses in red deer habitat selection. *Ecology* 90: 699–710.
- HIRZEL A. H. & LE LAY G. 2008. Habitat suitability modelling and niche theory. *Journal of Applied Ecology* 45: 1372–1381.
- HWANG H. S., SON S. H., KANG H. & RHIM S. J. 2014. Ecological factors influencing the winter abundance of mammals in temperate forest. *Folia Zoologica* 63: 296–300.
- JUNG J., SHIMIZU Y. & OMASA K. 2011. Analysing habitat characteristics for Korean water deer (*Hydropotes inermis argyropus*) in Korea using remote sensing and landscape metrics. *Eco Engineering* 23: 75–80.
- KIE J. G., EVANS C. J., LOFT E. R. & MENKE J. W. 1991. Foraging behavior by mule deer: the influence of cattle grazing. *Journal of Wildlife Management* 55: 665–674.
- KIM B. J. & LEE S. D. 2011. Home range study of the Korean water deer (*Hydropotes inermis argyropus*) using radio and GPS tracking in South Korea: comparison of daily and seasonal habitat use pattern. *Journal of Ecology and Field Biology* 34: 365–370.
- KIM B. J., LEE N. S. & LEE S. D. 2011. Feeding diets of the Korean water deer (*Hydropotes inermis argyropus*) based on a 202 bp rbcL sequence analysis. *Conservation Genetics* 12: 851–856.
- KIM B. J., OH D. H., CHUN S. H. & LEE S. D. 2011. Distribution, density, and habitat use of the Korean water deer (*Hydropotes inermis argyropus*) in Korea. *Landscape and Ecological Engineering* 7: 291–297.
- KOREA FOREST SERVICE. 2012. Characteristics of forest structure and wildlife caused by forest practices. Korea Forest Service. Daejeon, Korea. 170 p.
- LEE W. S., PARK C. R., RHIM S. J., HUR W. H., CHUNG O. S., CHOI C. Y., PARK Y. S. & LEE E. J. 2017. *Wildlife ecology and management*. Second edition. Life Science Publishing. Seoul, Korea. 342 p.
- LINGLE S. 2002. Coyote predation and habitat segregation of white-tailed deer and mule deer. *Ecology* 83: 2037–2048.
- LIKENS G. E. & BORMANN F. H. 1999. *Biogeochemistry of a forested ecosystem*. Second edition. Springer-Verlag. New York, USA. 163 p.
- LONE K., LOE L. E., GOBAKKEN T., LINNELL J. D. C., ODDEN J., REMMEN J. & MYSTERUD A. 2014. Living and dying in a multi-predator landscape of fear: roe deer are squeezed by contrasting pattern of predation risk imposed by lynx and humans. *Oikos* 123: 641–651.
- MANCINELLI S., PETERS W., BOITANI L., HEBBLEWHITE M. & CAGNACCI F. 2015. Roe deer summer habitat selection at multiple spatio-temporal scales in an alpine environment. *Hystrix* 26: 132–140.
- MÄNSSON J., ANDRÉN H. & SAND H. 2011. Can pellet counts be used to accurately describe winter habitat selection by moose *Alces alces*? *European Journal of Wildlife Research* 57: 1017–1023.
- MOESLUND J. E., ARGE L., BØCHER P. K., DALGAARD T. & SVENNING J. C. 2013. Topography as a driver of local terrestrial vascular plant diversity patterns. *Nordic Journal of Botany* 31: 129–144.
- MYSTERUD A. 1996. Bed-site selection by adult roe deer *Capreolus capreolus* in southeastern Norway during summer. *Wildlife Biology* 2: 101–106.
- MYSTERUD A. 1999. Seasonal migration pattern and home range of roe deer (*Capreolus capreolus*) in an altitudinal gradient in southern Norway. *Journal of Zoology* 247: 479–486.
- MYSTERUD A., LIAN L. B. & HJERMANN D. Ø. 1999. Scale-dependent trade-offs in foraging by European roe deer (*Capreolus capreolus*) during winter. *Canadian Journal of Zoology* 77: 1486–1493.
- MYSTERUD A. & OSTBYE E. 1999. Cover as a habitat element for temperate ungulates: effects on habitat selection and demography. *Wildlife Society Bulletin* 27: 385–394.
- PARK S. J., RHIM S. J., LEE E. J., LEE W. S. & MAGUIRE C. C. 2014. Home range, activity patterns, arboreality, and day refuges of the Korean wood mouse *Apodemus peninsulae* (Thomas, 1907) in a temperate forest in Korea. *Mammal Study* 39: 209–217.
- POMPILIO L. & MERIGGI A. 2001. Modelling wild ungulate distribution in alpine habitat: A case study. *Italian Journal of Zoology* 68: 281–289.
- RATIKAINEN I. I., PANZACCHI M., MYSTERUD A., ODDEN J., LINNELL J. & ANDERSEN R. 2007. Use of winter habitat by roe deer at a northern latitude where Eurasian lynx are present. *Journal of Zoology* 273: 192–199.
- RHIM S. J. 2013. Hazel grouse winter habitat selection and conservation in temperate forest. *Forest Ecology and Management* 295: 38–42.
- RHIM S. J. & LEE W. S. 2007. Influence of forest fragmentation on the abundance of mammals in Mt. Chirisan National Park, South Korea. *Journal of Wildlife Management* 71: 1404–1408.
- RHIM S. J., SON S. H., HWANG H. S., KANG J. H., SUNG J. H., PARK G. E. & PARK C. R. 2015. Characteristics of mammal abundance relative to habitat variables in temperate forests. *Forest Science and Technology* 11: 61–64.
- SON S. H., HWANG H. S., LEE J. K., EOM T. K., PARK C. R., LEE E. J., KANG J. H. & RHIM S. J. 2017. Influence of tree thinning on the abundance of mammals in a Japanese larch *Larix kaempferi* plantation. *Animal Cells & Systems* 21: 70–75.
- WIENS J. A. 1989. Spatial scaling in ecology. *Functional Ecology* 3: 385–397.
- WON C. M. & SMITH K. G. 1999. History and current status of mammals of the Korean peninsula. *Mammal Review* 29: 3–36.
- YOU B. H. 2000. Wildlife take after the green. *Dareunsang*

Publishing. Seoul, Korea. 244 p.

ZHANG E. 2000. Daytime activity budgets of the Chinese water deer. *Mammalia* 64: 163–172.

ZUUR A., IENO E. & ELPHICK C. 2010. A protocol for data exploration to avoid common statistical problems. *Methods in Ecology and Evolution* 1: 3–14.

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