Lesn. Cas. For. J. 60 (2014) 199–204 DOI: 10.1515/forj-2015-0001

PÔVODNÁ PRÁCA – ORIGINAL PAPER

Lesnícky časopis - Forestry Journal
http://www.nlcsk.sk/fj/

Daily activity rhythm and habitat use of the semi-free European bison herd during the growing season

Denní aktivita a využití prostředí zubrem evropským (*Bison bonasus*) během vegetační sezóny

Jaroslav Červený[1], Miloš Ježek[1]*, Michaela Holá[1], Miloslav Zikmund[1], Tomáš Kušta[1], Vladimír Hanzal[1], Rudolf Kropil[2]

[1]Czech University of Life Sciences Prague, Faculty of Forestry and Wood Sciences, Kamýcká 129, CZ – 165 21 Praha, Czech Republic
[2]Technical University in Zvolen, Faculty of Forestry, T. G. Masaryka 24, SK – 960 53 Zvolen, Slovakia

Abstract

The European bison (*Bison bonasus*) became extinct in the wild in the 20th century. Due to successful reintroductions of captive individuals, the free-ranging bison population has been steadily increasing. However, the population consists of small and isolated herds whose survival depends on creating larger and connected populations. Detailed knowledge of movement and habitat use in human-dominated landscape is essential for further successful reintroductions of the European bison. Therefore, we studied daily activity and habitat use of the semi-free European bison herd in the hunting enclosure of Židlov from April to September 2014. The lead cow of the herd was fitted with a GPS collar equipped with GSM module. The average home range size of the herd was 29.5 km^2 and the average daily utilisation area was 0.5 km^2. Forested habitats were preferred during the day (Rayleigh test: $Z = 107.31$; $p < 0.0001$) whereas idle lands (i.e. former shooting ranges now dominated by a mixture of pioneer tree species, hawthorn and grasslands) during the night (Rayleigh test: $Z = 214.451$; $p < 0.0001$). The bison herd did not show any clear preference for a particular forest type (i.e. coniferous, deciduous, different age classes). Additional knowledge on year-long patterns of movement and habitat use is needed to ensure the success of reintroduction programmes.

Key words: *Bison bonasus;* GPS collar; daily moved distance; habitat preference

Abstrakt

Zubr evropský (*Bison bonasus*) vyhynul ve volné přírodě na začátku 20-tého století. Následně byl ze zajetí reintrodukován do několika oblastí střední Evropy a od té doby jeho početnost roste. Nicméně jeho současný výskyt je koncentrován pouze do malých populací a jejich další přirozený vývoj je závislý na vytvoření konceptu vzájemného propojení. Pro vytvoření a realizaci tohoto konceptu je kladen důraz na znalost prostorové aktivity zubra a jeho preference prostředí. Tyto znalosti budou esenciální zejména v oblastech uvažované reintrodukce v typech krajiny intenzivně využívaných lidskou činností. Naše studie se proto zabývá denní aktivitou a využitím území reintrodukovaného stáda zubrů v oboře Židlov ve vegetačním období (duben – září 2014). Byla sledována hlavní samice, označena GPS obojkem s GSM modulem. Domovský okrsek stáda během celého sledovaného období byl 29,5 km^2 a velikost průměrného denního využívaného území bylo 0,5 km^2. Statisticky signifikantní rozdíl byl ve využívání různých typů porostů, kdy během dne zubři využívali lesní prostředí (Rayleigh test: $Z = 107.31$; $p < 0.0001$) a během noci naopak otevřené porosity (Rayleigh test: $Z = 214.451$; $p < 0.0001$). Zubří stádo nevykazovalo výrazné preference pro jednotlivé typy porostů (jehličnaté, listnaté, věkové třídy). Další studie zabývající se prostorovým chováním zubra a jeho variability během celého roku jsou pro další úspěšné reintrodukce tohoto druhu nezbytné.

Klíčová slova: *Bison bonasus;* GPS obojek; denní ušlá vzdálenost; preference prostředí

1. Introduction

The European bison (*Bison bonasus*) is the largest European free-ranging herbivore (IUCN 2014). Historically, its range covered almost all of Europe, extending from the Pyrenees through the southern Sweden to the Volga River and the Caucasus (Heptner et al. 1988). The expansion of human population, subsequent habitat loss, and overhunting drove the bison population out of the natural habitats and the species gradually became extinct throughout most of its range. The last wild animals were shot in the Białowieża Forest in 1919 and in the Caucasus in 1927 (Dostál et al. 2012).

In an effort to save the species, the International Society for the Protection of European bison was established in Germany in 1923. Its first objective was to perform an inventory of all individuals still being alive in European reserves and zoos. The inventory found only 54 (29 males and 25 females) European bison with proven genetic purity (Olech 2009). Subsequent reintroductions of European bison into the wild started in the Białowieża Forest in 1952 (Krasiński 1978) and continued in other parts of Europe (Pucek et al. 2004). As a result of these reintroductions and intensive conservation management, the population of free-ranging bison has now grown to about 2,701 individuals, and further approximately 1,530 individuals live in captivity (EBCC 2014). The largest free-living populations are distributed mainly in Poland, Belarus, Ukraine, and Russia (EBCC 2014). Despite the fact that the bison population has increased during the 20th century, the species still faces an uncertain future (Pucek

*Corresponding author. Miloš Ježek, e-mail: jezekm@fld.czu.cz

et al. 2004). Low genetic diversity, geographic isolation of existing herds, and poaching are the main threats for the current population of the European bison (Olech & Perzanowski 2002; Perzanowski et al. 2004; Pucek et al. 2004). Therefore, the species is still classified as vulnerable according to the IUCN Red List (IUCN 2014).

The main objective of the present conservation strategy is to create conditions suitable for the long-term survival of wild bison populations by increasing the genetic diversity of existing populations and extending their distribution range (Pucek et al. 2004; Krasińska & Krasiński 2007). The conservation success will depend on increasing the population size and linking local isolated populations into a large meta-population through natural or assisted transfers of animals (Pucek et al. 2004; Krasińska & Krasiński 2007; Ziółkowska et al. 2012). This requires increasing the connectivity of subpopulations occurring especially in Poland, Slovakia and Ukraine (Dalszcyk & Bunevich 2009), as well as extending the reintroduction attempts into other suitable habitats across Central and Eastern Europe (Pucek et al. 2004). Several studies have assessed the viability of European bison populations and identified the candidate areas suitable for reintroductions of bison herds throughout Europe (Kuemmerle et al. 2011; Ziolkowksa et al. 2012; Kerley et al. 2012; Kuemmerle et al. 2012). The need for such studies is determined by profound changes and processes undergone by European landscape during the last century. Increasing human population and agricultural intensification have resulted in substantial decrease of forest cover and landscape fragmentation (Matson et al. 1997). These changes have markedly contributed to extirpations of many large mammals, including the European bison (Stoate et al. 2001). Nowadays, forest cover has been steadily increasing in Europe (Bengtsson et al. 2000), and particularly in some rural areas of the former Soviet Union the anthropogenic pressure has decreased (Kuemmerle et al. 2008). Therefore, suitable habitats for bison reintroductions have been expanding (Kuemmerle et al. 2011). Although European bison are generally considered as forest specialists (Sztolcman 1926), several studies have suggested that they are able to adapt to more open and fragmented landscapes (Balčiauskas 1999; Pucek et al. 2004). However, for the successful conservation and further expansion of the species, additional information on detailed habitat use is needed. Suitable candidate areas (i.e. high-quality areas with low conflict in land use) for bison reintroductions were identified at a continental scale in the study of Kuemmerle et al. (2011). They evaluated the suitability of habitats using herd range maps for all 36 existing free-ranging European bison herds with the maximum entropy approach and took into account factors such as land cover, topography, and human disturbance. The most promising candidate areas for European bison meta-populations were found in Eastern Europe. In the case of suitable candidate areas in the Czech Republic, the model identified four sites covering a total area of 10,060 km^2.

The expected increase in the population size associated with reintroductions and expansion of existing populations substantially increases the risk of upcoming human-bison conflicts (Hofman-Kamińska & Kowalczyk 2012). However, studies evaluating environmental impacts of reintroduced bison populations and associated human dimensions are still rare (Decker et al. 2010; Hofman-Kamińska & Kowalczyk 2012; Balčiauskus & Kazlauskas 2014). Higher bison densities in forest ecosystems may result in their expansions to open habitats (i.e. mainly agricultural) and thus cause conflicts with farmers due to substantial losses of agricultural crops (Hofman-Kamińska & Kowalczyk 2012). As in the case of bison populations in Poland, the costs compensating farmers for the damage caused by bison have been increasing from year to year and reached over 90,000 Euro in 2010. Despite that, the presence of bison in Polish forests is still not fully accepted by involved local communities (Hofman-Kamińska & Kowalczyk 2012). In Germany for example, public attitudes toward reintroducing the European bison are rather positive (Decker et al. 2010). All these aspects need to be taken into account as a part of the reintroduction programmes to minimise the possible conflict between bison populations and all the stakeholders involved.

Regarding the status of the European bison in the Czech Republic, there are currently 43 captive individuals held in the zoological gardens and farms (EBCC 2014). One semi-free living herd can be found in the large hunting enclosure (37.95 km^2) of Židlov, where 5 individuals were released in 2011. Concerning the neighboring countries of the Czech Republic, the geographically closest bison herds occur in Slovakia, where 5 individuals were reintroduced to the Poloniny National Park in 2004 and since then the herd has grown to about 20 individuals. A semi-free bison herd can also be found in Germany (Dostál et al. 2012).

The long-term aim of Czech wildlife management agencies and policy decision making bodies is to have a free-ranging herd of the European bison in one of the military training areas in the Czech Republic as these represent most suitable habitats for the species (Kuemmerle et al. 2011). The first step in fulfilling this aim was the reintroduction of the bison herd into the Židlov enclosure in order to get deeper knowledge of ecology of the species under controlled conditions resembling natural conditions as much as possible. The leading cow of the herd was fitted with a GPS collar to assess the spatial behavior and habitat use of the herd. In this study we examine daily activity rhythm and habitat use of the herd currently consisting of 17 individuals in the Židlov enclosure.

2. Material and Methods

2.1. Study area

The hunting enclosure of Židlov (50°36'33.258"N, 14°50’33.421"E) covers nearly 38 km^2 and is located in the northern part of the Czech Republic at the territory of a former military training area. The enclosure was established in 2000 and is now owned and managed by the Military Forests and Estates of the Czech Republic, s.e. Forest stands, dominated by pine, spruce, and beech, cover 55% of the enclosure. Coniferous stands cover 88% of the enclosure and deciduous stands 12%. Idle lands (i.e. former shooting ranges now being spontaneously developed and dominated by a mixture of pioneer tree species, hawthorn and grasslands) occupy 38% of the enclosure. The proportion of arable lands covered by oats and clover is 5%.

The bison herd in the Židlov enclosure was initiated in 2011 when a single male from the Kampinos National Park and four females from the Białowieża Forest were released in the area. The herd has now grown to 17 individuals (11 females and 6 males). The other species of wild ungulates occurring in the enclosure are red deer (*Cervus elaphus*), moufloun (*Ovis musimon*), wild boar (*Sus scrofa*), roe deer (*Capreolus capreolus*), and fallow deer (*Dama dama*). Large predators are not present in the enclosure, but a pack of wolves (*Canis lupus*) was spotted nearby in 2014.

2.2. Data collection

During the growing season 2014 (from April to September), we tracked the movements of the herd by fitting a GPS collar equipped with GSM module to the lead cow. We used the collar produced by VECTRONIC Aerospace GmbH in Germany (model type GPS Plus 5D weighing 1.13 kg). The collar was set to record GPS locations (~ 10 m accuracy) at 30 min intervals. The GPS locations were transmitted daily via the GSM module to a secure online database available at http://zver.agris.cz/en/, where the data were stored and backed up without the need of retrieving the collar (Jarolímek et al. 2012; Jarolímek et al. 2014). As a measure of the accuracy of each GPS location, the collar also recorded a dilution of precision (DOP) value, i.e. a value describing the distribution of satellites in space, and their geometry. Lower DOP values indicate higher location accuracy because of a wider angular separation between the satellites (Langley 1999).

2.3. Data management and statistical analyses

In order to increase the location accuracy, all location estimates with DOP > 6 were removed from the dataset (Lewis et al. 2007; Frair et al. 2010). To maintain the data homogeneity, only the GPS locations recorded every 30 minutes were used for the analysis. When the time interval between the two GPS locations was longer, the locations were removed, since in such cases the distances might be distorted. The moved distances were calculated as the shortest distance between the two GPS locations recorded at 30-minute intervals, though the real distance could have been longer. The distances walked within 30-minute intervals were then divided into the following length categories: 0–25 m (i.e. no spatial activity), 25–50 m, 50–75 m, 75–100 m, 100–150 m, 150–200 m (i.e. high spatial activity). The Oriana 4.02 software (Kovach Computing) and circular statistics were used to examine the distribution of these distances walked within 30-minute intervals during the 24-hour cycle (Lehner 1996). Significant deviations from random distributions were investigated using the Rayleigh test of circular statistics.

Possible differences in the average daily moved distances between the day and night were evaluated using Student´s t-test. The Kruskal-Wallis test was used to determine possible differences in the size of daily utilisation area (DUA) between the individual months of the study (i.e. April–September). Significant results are reported for $P < 0.05$.

The average home range of the bison herd during the growing season was calculated in ArcGIS Desktop10 software (ESRI 2010) using the method of minimum convex polygon 100% (Mohr 1947). The ArcGIS Desktop 10 software was also used to determine the habitat use of the bison herd. We joined the GPS locations with the habitat model containing detailed information on land use in the hunting enclosure. We compared the habitat found at each location derived from the GPS collars with the overall habitat of the enclosure and determined the habitat preferences.

3. Results

During the 24-hour cycle the herd usually travelled very short distances within a 30-minute interval. More than 59% of time was spent with no substantial spatial activity of the herd (Fig. 1; categories 0–25 m and 25–50 m). The substantial movements, i.e. movements longer than 200 m within 30-min intervals, were observed only in 11% of cases (Fig. 1 category 200m+), with the longest distance being 2.2 km.

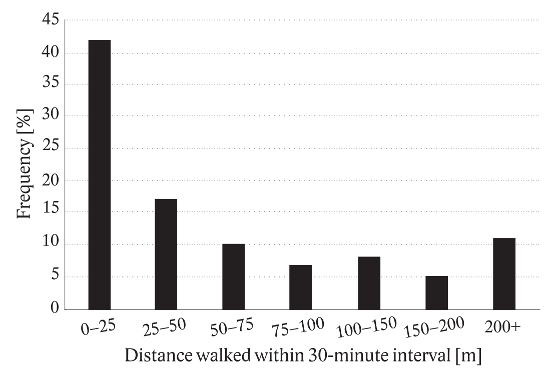

Fig. 1. Distribution of distances walked by the European bison herd in a 30-minute interval within individual categories in the hunting enclosure from April to September.

The difference in the average daily moved distance (hereinafter as ADMD reported as mean ± SD) within a 30-minute interval during the day (i.e. 06:00–18:00h; ADMD = 90 ± 127 m) and during the night (i.e. 18:00–06:00h; ADMD = 72 ± 127 m) was significant (Student´s t–test: t = 5.486; $p < 0.0001$; Fig. 2).

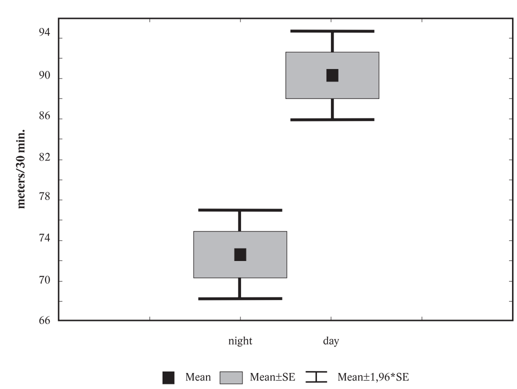

Fig. 2. The average daily moved distance within a 30-minute interval by the European bison herd in the day (06:00–18:00 h) and night (18:00–06:00 h).

Consequently, the bison herd was more active during the day which is also evidentfrom the distribution of moved distances throughout the 24-hour cycle (Fig. 3). In the category of 0–25 m (i.e. no movement), there is a clear dependency with a daytime (Rayleigh test: Z = 88.296, p < 0. 0001), with the grand mean vector being at 02:43 h. Therefore, we can conclude that the herd was the least active during the second half of night (i.e. 0:00–6:00 h; Fig. 3a). On the other hand, the spatial activity on short distances (categories 25–50 m and 50–75 m, i.e. this spatial behavior can be classified as an intensive grazing) was distributed evenly during the whole day. In addition, the "real transfer", when the herd moved more than 75 m in 30 minutes, was concentrated in two day periods, i.e. at dawn (18:00 h) and at dusk (06.00 h). Therefore, the data demonstrated a bimodal distribution of this type of spatial activity (Fig. 3d, e, f); Rayleigh test: 100–50 m category: Z = 6.013; p = 0.002; 150–200 m category: Z = 10.092; p < 0. 0001; 200 m+ category: Z = 34.855; p < 0. 0001).

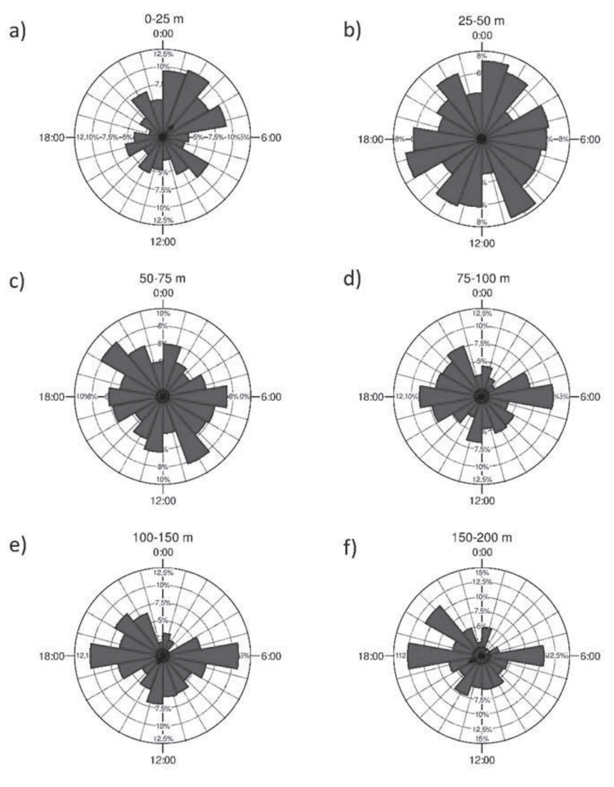

Fig. 3. Circular diagrams of distribution of the moved distances by the European bison herd throughout the 24-hour cycle in different length categories.

Regarding the average size of home range during the growing season (April–September), the herd used a territory of 29.5 km² (calculated by Minimum Convex Polygon 100% method). Therefore, the herd did not use the whole area of the hunting enclosure (37.95 km²). The average daily utilisation area (DUA) was 0.5 km². The difference between individual months was not statistically significant (Kruskal-Wallis test: H = 13.224; p = 0.7959). The lowest average DUA was recorded in June, whereas the highest average DUA was in April. The maximum DUA was recorded in April (2.34 km²), July (2.08 m²), and August (1.98 m²). In 74% of the days, DUA reached 0.5 km², in 12% it ranged between 0.5 and 1 km², and only in 15% of the days it was greater than 1 km² (Fig. 4).

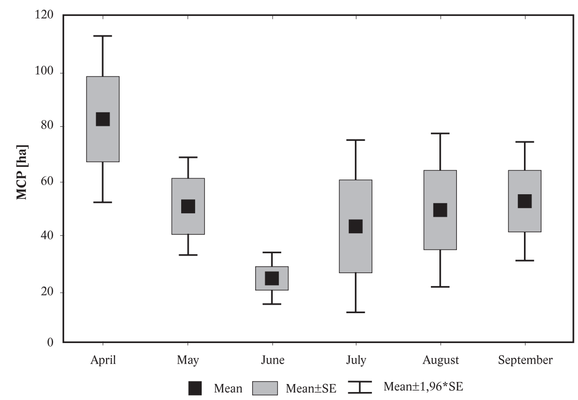

Fig. 4. The average size of daily utilisation area (DUA) of the European bison herd during the period April–September.

The herd spent more than 58% of time in forested habitats. In 40% of time it was located in idle lands. The habitat preference was however dependent on a day time. The forest areas were preferred during the day (Fig. 5, Rayleigh test: Z = 107.31; p < 0. 0001), with the grand mean vector at 14:12 h.

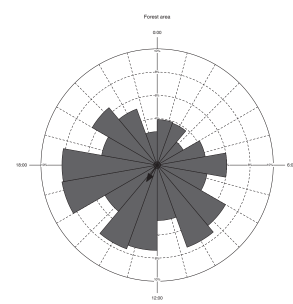

Fig. 5. Circular diagram showing the distribution of the GPS locations of the European bison herd during 24-hour cycle recorded in the forested habitat.

The idle lands were, on the other hand, preferred during the night (Fig. 6, Rayleigh test: Z = 214.451; p < 0. 0001), with the grand mean vector at 02:17 h.

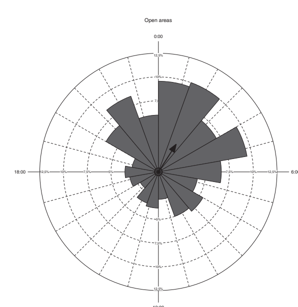

Fig. 6. Circular diagram showing the distribution of the GPS locations of the European bison herd during 24-hour cycle recorded in idle lands.

The forest areas older than 100 years were visited most frequently (44% of the time), followed by 40–60-year-old forest areas (19%), 60–80-year-old (11%), 20–40–year-old (7%) and 0–20-year-old forest areas (6%). The herd was predominantly located in coniferous stands (88%) compared to deciduous stands (12%), and showed the preferences for stands dominated by pine (56%), followed by spruce (33%), birch (8%), oak (2%), and larch (1%).

4. Discussion

The main goal of the current conservation strategy of the European bison is to create a large and long-term viable well--connected meta-population (Pucek et al. 2004; Krasińska & Krasiński 2007). Nowadays, European bison occupy less than 1% of its former range (Pucek at al. 2004). Therefore, to fulfill the conservation goal would mean to reintroduce and substantially increase the population size in areas affected by humans. Gaps in the knowledge about detailed habitat use and preferences in human dominated landscape have been the main obstacles for present conservation planning of the European bison. Our study provides information on the daily activity rhythm and habitat use of the semi-free European bison herd consisting of 17 individuals in the large hunting enclosure in the Czech Republic during the period April–September.

Our results indicate that the spatial behavior of the semi-free bison herd occupying the Central European enclosure was not substantially different compared to free-ranging herds inhabiting areas less affected by humans, i.e. the Carphatians and the Białowieża Forest (Kuemmerle et al. 2012; Kowalczyk et al. 2013). The average home range size found here was also comparable with the average home ranges of the free-ranging populations (Perzanowski et al. 2012; Kowalczyk et al. 2013).

The bison herd in our study preferred forested habitats during the day and idle lands (i.e. former shooting ranges now dominated by a mixture of pioneer tree species, hawthorn and grasslands) during the night. This finding supports an assumption that the European bison occupying the Central European landscape tends to be a forest specialist (Verkaar et al. 2004). Nevertheless, previous studies have indicated that European bison prefer open habitats (Pucek et al. 2004; Krasińska and Krasiński 2007; Daleszczyk & Bunevich 2009; Kerley et al. 2012) and that the amount of time spent in forested habitats is determined by threat avoidance and not habitat preference (Drucker and Bocherens 2009). In the case of the European bison, the threat avoidance could have been caused by hundreds of years of pursuit and attempts to exterminate bison herds, which consequently retreated to large forest habitats. This theory is also supported by our results and the differences in the choice of habitats between night- and day-time.

We did not find any clear preference for a particular forest type (i.e. coniferous or deciduous). Although previous studies showed that bison prefer deciduous forests (e.g. Krasińska and Krasiński 2007; Kuemmerle et al. 2011), Brandtberg and Dabelsteen (2013) reported that the reintroduced bison at a Danish island preferred coniferous forest stands during the growing season.

Our results support the idea of bison reintroduction to free nature, especially to military training areas. Such areas are sufficiently large to allow natural behaviour of a herd. However, it is still necessary to perform additional research and in particular, it is essential to evaluate spatial behavior throughout the whole year and evaluate possible differences between different seasons. It is also important to test possible tools, by which it would be possible to influence spatial activity of bison herds (such as supplementary feeding). In Central European conditions such knowledge is essential to prevent potential human-bison conflicts.

Acknowledgements

This study was supported by the Ministry of Agriculture of the Czech Republic, Grant No. QJ1220314 and by Czech University of Life Sciences, Grant No. 11150/1313/3113.

References

Balčiauskas, L., 1999: European bison (*Bison bonasus*) in Lithuania: status and possibilities of range extension. Acta Zoologica Lituanica, 3:3–18.

Balčiauskas, L., Kazlauskas, M., 2014: Forty years after reintroduction in a suboptimal landscape: public attitudes towards European bison. European Journal of Wildlife Research, 60:155–158.

Bengtsson, J., Nilsson, S. G., Franc, A., Menozzi, P., 2000: Biodiversity, disturbances, ecosystem function and management of European forests. Forest Ecology and Management, 132:39–50.

Brandtberg, N. H., Dabelsteen, T., 2013: Habitat selection of two European bison (*Bison bonasus*) on the Danish island Bornholm. European Bison Conservation Newsletter, 6:73–80.

Daleszczyk, K., Bunevich, A. N., 2009: Population viability analysis of European bison populations in Polish and Belarusian parts of Białowieża Forest with and without gene exchange. Biological Conservation, 142:3068–3075.

Decker, S. E., Bath, A. J., Simms, A., Lindner, U., Reisinger, E., 2010: The Return of the King or Bringing Snails to the Garden? The Human Dimensions of a Proposed Restoration of European Bison (*Bison bonasus*) in Germany. Restoration Ecology, 18:41–51.

Dostál, D., Jirků, M., Konvička, M., Čížek, L., Šálek, M., 2012: Návrat zubra evropského (*Bison bonasus*) do České republiky. Česká krajina o.p.s. Kutná Hora.

Drucker, D. G., Bocherens, H., 2009: Carbon stable isotopes of mammal bones as tracers of canopy development and habitat use in temperate and boreal contexts. In: Creighton, J.D., Roney, P. J. (eds.): Forest canopies: forest production, ecosystem health and climate conditions. Nova Science Publishers, Hauppauge, NY, p. 103–109.

EBCC, 2014: European Bison Conservation Center. Population size of E. bison kept in captive and free-living herds. Available at: http://www.bison-ebcc.eu/bison_data_2014.pdf.

Frair, J. F., Fieberg, J., Hebblewhite, M., Cagnacci, F., Decesare, N. J., Pedrotti, L., 2010: Resolving issues of imprecise and habitat – biased locations in ecological analyses using GPS telemetry data. Philosophical Transactions of the Royal Society B-Biological Sciences, 365:2187–2200.

Hofman-Kamińska, E., Kowalczyk, R., 2012: Farm Crops Depredation by European Bison (*Bison bonasus*) in the Vicinity of Forest Habitats in Northeastern Poland. Environmental Management, 50:530–541.

Heptner, V. G., Nasimovitch, A. A., Bannikov, A. G., 1988: Wisent. 557–599, In: Heptner, V. G., Nasimovitch, A. A., Bannikov, A. G. (eds.): Mammals of the Soviet Union, I. Artiodactyla and Perissodactyla. Washington, D.C., 1147 p.

IUCN, 2014: The IUCN Red List of Threatened Species. Available at: http://www.iucnredlist.org/details/full/2814/0.

Jarolímek, J., Masner, J., Ulman, M., Dvořák, S., 2012: Cloven-hoofed animals spatial activity evaluation methods in Doupov Mountains in the Czech Republic. AGRIS on-line Papers Economics and Informatics, 4:41–48.

Jarolímek, J., Vaněk, J., Ježek, M., Masner, J., Stočes, M., 2014: The telemetric tracking of wild boar as a tool for field crops damage limitation. Plant, Soil and Environment, 60:418–425.

Kerley, G. I. H., Kowalczyk, R., Cromsigt, J. P. G. M., 2012: Conservation implications of the refugee species concept and the European bison: king of the forest or refugee in a marginal habitat? Ecography, 35:519–529.

Kowalczyk, R., Krasińska, M., Kamiński, T., Górny, M., Struś, P., Hofman-Kamińska, E. et al., 2013: Movements of European bison (*Bison bonasus*) beyond the Białowieza Forest (NE Poland): range expansion or partial migrations? Acta Theriologica, 58:391–401.

Krasińska, M., Krasiński, Z. A., 2007: European Bison, a nature monograph. Mammal Research Institute, Polish Academy of Sciences, Bialowieza, 221 p.

Krasiński, Z. A., 1978: Dynamics and structure of the European bison population in the Białowieża Primeval Forest. Acta Theriologica, 23:13–48.

Kuemmerle, T., Hostert, P., Radeloff, V.C., van der Linden, S., Perzanowski, K., Kruhlov, I., 2008: Cross-border comparison of post-socialist farmland abandonment in the Carpathians. Ecosystems, 11:614–628.

Kuemmerle, T., Radeloff, V. C., Perzanowski, K., Kozlo,P., Sipko, T., Khoyetskyy, P. et al., 2011: Predicting potential European bison habitat across its former range. Ecological Applications, 21:830–843.

Kuemmerle, T., Hickler, T., Olofsson, J., Schurgers, G., Radeloff, V. C., 2012: Reconstructing range dynamics and range fragmentation of European bison for the last 8000 years. Diversity and Distributions, 18:47–59.

Langley, R. B., 1999: Dilution of precision. GPS World 10:52–59.

Lehner, P. N., 1996: Spatial orientation and time: circular statistics and spatial patterns. In: Lehner, P. N. (ed.): Handbook of ethological methods. Cambridge University Press, p. 485–521.

Lewis, J. S., Rachlow, J. L., Garton, E. O., Vierling, L. A., 2007: Effects of habitat on GPS collar performance: using data screening to reduce location error. J. Appl. Ecol., 44:663–671.

Matson, P. A., Parton, W. J., Power, A. G., Swift, M. J., 1997: Agricultural intensification and ecosystem properties. Science, 277:504–509.

Mohr, C. O., 1947: Table of equivalent populations of North American small mammals. American Middle Naturalist, 37:223–249.

Olech, W., Perzanowski, K., 2002: A genetic background for reintroduction program of the European bison (*Bison bonasus*) in the Carpathians. Biological Conservation, 108:221–228.

Olech, W. 2009: The changes of founders' number and their contribution to the European bison population during 80 years of species' restitution. European Bison Conservation Newsletter, 2:54–60.

Perzanowski, K., Olech, W., Kozak, H. 2004: Constraints for re-establishing a meta-population of the European bison in Ukraine. Biological Conservation, 120:345–353.

Pucek, Z., Belousova, I. P., Krasińska, M., Krasiński, Z. A., Olech, W., 2004: European bison. Status survey and conservation action plan. IUCN/SSC Bison Specialist Group. IUCN, Gland, Switzerland.

Stoate, C., Boatman, N. D., Borralho, R. J., Rio Carvalho, C., de Snoo, G. R., Eden, P., 2001: Ecological impacts of arable intensification in Europe. Journal of Environmental Management, 63:337–365.

Sztolcman, J. 1926: European bison its history habits and future. Warszawa: The Central Union of Polish Associations of Hunting.

Verkaar, E. L. C., Beeke, M., Hanekamp, E., Nijman, I. J., Lenstra, J. A., 2004: Maternal and paternal lineages in interbreeding bovine species. Is wisent a hybrid species? Mol. Biol. Evol., 21:1165–1170.

Ziółkowska, E., Ostapowicz, K., Kuemmerle, T., Perzanowski, K., Radeloff, V. C., Kozak, J. ,2012: Potential habitat connectivity of European bison (*Bison bonasus*) in the Carpathians. Biological Conservation, 146:188–196.