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Movement ecology of brown bears (*Ursus arctos*) in the Romanian Eastern Carpathians

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Abstract

Brown bear movement patterns are driven by their opportunistic feeding behaviour, with their complex life history and seasonality playing an important role in habitat selection. Within a large unfragmented forest habitats persisting over decades in the Romanian Carpathians and a prohibitive hunting management during 40 years of communist centralised game management, information about brown bear movements and spatial ecology is lacking. Using data obtained from 13 brown bears fitted with GPS telemetry collars, we estimated home ranges and core activity areas and we investigated the daily, seasonal and altitudinal movements of brown bears in the Eastern Romanian Carpathians and surrounding high hills. The median MCP95% home ranges of brown bears was 629.92 km^2 and the median size of core activity areas (estimated as 50% kernel density) was 36.37 km^2, with no significant differences between males and females. The mean daily distance travelled, measured as daily displacement length, was 1818 m and an analysis of seasonal movements indicated significant differences between seasons (greatest movements during the Hyperphagia season). The GPS-collared brown bears travelled between a minimum altitude measured at ~234 m and a maximum at ~1634 m. Analysing the spatial overlap between the estimated home range and the game management units (GMU) limits, we obtained a median number of 8 GMUs overlapping totally or partially with estimated home range polygons. Our study, using GPS telemetry, highlights the complex spatial ecology of the brown bear in the Romanian Carpathians, with larger home range size than those estimated in other European brown bear populations and with daily movements that vary by season and within a large altitude range. Our study supports the implementation of brown bear monitoring at a regional scale, rather than focusing on county level GMUs as the monitoring unit.

Keywords
Daily movements, home range, Romanian Carpathians, *Ursus arctos*

Introduction

Understanding animal movement patterns is crucial for wildlife management and conservation (Kernohan et al. 2001). Movements of individuals in their forays for food, switching between habitats, defending cubs or food resources, are of high interest for understanding the ecology of brown bears in heterogeneous landscapes (Martin et al. 2013). The use of telemetry to obtain movement data has been adopted in brown bear research studies for decades, e.g., movement patterns in Kodiak Island or denning ecology in Yellowstone (Berns and Hensel 1972, Craighead and Craighead 1972). Telemetry was also used to provide information about brown bear habitat suitability in the Alps (Guthlin et al. 2011) or predicting human-bear conflicts in the Dinaric Mountains (Jerina et al. 2012). Analysis of animal movement data leads to a deeper understanding of key environmental resources required for population persistence (Margules and Pressey 2010), which aids resource managers in developing wildlife management strategies. Worldwide, brown bear population management (e.g., for North American, Dinaric, Scandinavian, Alpine brown bear populations) has been heavily influenced by the results of telemetry studies over the past four decades. In Croatia, telemetry studies have been critical for quantifying home range sizes, the overlap between individual home ranges, as well as the gender differences in home range sizes (Huber and Roth 1993). These data have been used in developing the brown bear management plan for the Republic of Croatia.

Brown bear movement patterns and spatial ecology are driven by their complex life history and seasonality plays an important role in their selection of habitats (Pop et al. 2018). Brown bears are opportunistic omnivores (Bojarska and Selva 2012, Kavcic et al. 2015) and their movements are heavily influenced by food resource availability (Nielsen et al. 2006, Stofik et al. 2013, Ciucci et al. 2014, Kavcic et al. 2015). In addition to food availability, other factors such as reproductive stage, den site availability or avoidance of conspecifics or predators, can affect the movement of individuals, which further poses challenges to understanding space use patterns (Nathan et al. 2008). Furthermore, environmental characteristics such as the reproduction period, air temperature or daylight length are also important in understanding the seasonality of brown bear movements (Nielsen et al. 2006, Martin 2009, Ware et al. 2013).

Large unfragmented forest habitats, persisting over decades in the Romanian Carpathians and surrounding high hills (Rozylowicz et al. 2011, Patru-Stupariu et al. 2013), and a prohibitive hunting management during 40 years of communist centralised game administration, had contributed to the maintenance of the largest and most stable European brown bear population (Chapron et al. 2014, Popescu et al. 2016). Romania's brown bear population inhabits the Carpathian mountains and surrounding high hills, which are characterised by low human density, but with intensive use of natural resources (e.g., timber and non-timber forest products) and livestock grazing. The highest brown bear densities, of up to 11 individuals/100 km^2 occur in Eastern Carpathians (Cazacu et al. 2014, Popescu et al. 2017). However, no studies to date have documented the movement ecology of Romanian brown bears at individual and population levels, leading to suboptimal management strategies (Popescu et al. 2016).

In Romania, brown bear ecology data are collected via opportunistic observations at feeding stations or using methodologies for counting track signs (Popescu et al. 2016) which lack statistical rigor and ignore the complex bear space use patterns (Lindstedt et al. 1986, Dahle and Swenson 2003). These monitoring deficiencies lead to a poor understanding of brown bear movements and habitat selection. Published data on space requirements or home range sizes of Romanian brown bears have been based on expert opinion and varied from 15–20 km^2 for an individual (Comsia 1961) to 200 km^2 for males and 50 km^2 for females (Maanen et al. 2002). Management decisions, made at the level of game management unit (GMU), may be suboptimal, given that GMUs are on average ~120 km^2 in size, thus potentially failing to capture the full extent of movement and space use of a single individual.

The aim of the study is to investigate brown bear movement ecology and space use in the Eastern Carpathians and surrounding high hills (Subcarpathians), Romania. We take advantage of a large dataset of Romanian brown bear GPS telemetry gathered between 2011 and 2015 within the framework of several large carnivore conservation projects to quantify annual and seasonal home ranges. We specifically evaluate whether differences in home range sizes exist between males and females, as well as between adults and sub-adults (Dahle and Swenson 2003). To test the validity of using GMUs for brown bear management, we analyse the overlap between individual home ranges, core activity centers and the game management units. Lastly, we investigate the daily, seasonal and altitudinal movements of brown bears across four different seasons with varying food availability (Ciucci et al. 2014, Roellig et al. 2014).

Methods

Study area

The Romanian Eastern Carpathians and Subcarpathians (elevation = 200–2303 m) (Figure 1) vary along an altitude gradient from urban and agricultural landscape on the low hills and main valleys, to deciduous, mixed and coniferous forests to subalpine shrubs and grasslands. Below 1200 m, habitats are dominated by deciduous forests with *Fagus sylvatica*, *Quercus* spp., *Carpinus* spp., *Acer* spp. and *Fraxinus* spp., in a heterogeneous landscape with secondary pastures, orchards and agricultural land. Mixed forests (*Picea abies, Abies alba, Fagus sylvatica*) are present mainly between 1000 m and

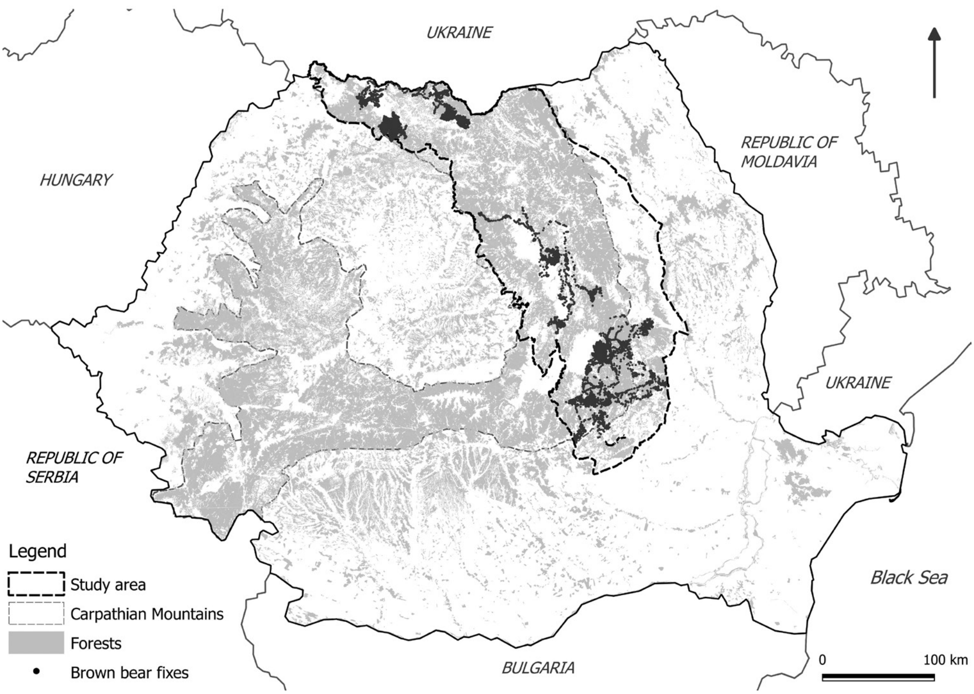

Figure 1. Study area (dashed area) in the Eastern Carpathians and Subcarpathians covering mountain and hill area; brown bear GPS fixes used in the study (black dots).

1400 m. Between 1400 m and 1700 m, forests are dominated by coniferous species (*Picea abies* and *Abies alba*) and *Vaccinium* spp. and *Rubus* spp. in the understory. The subalpine and alpine region (above 1700 m) are dominated by *Pinus mugo*, *Juniperus* spp. while the herbaceous layer is by *Festuca* spp., *Agrostius* spp. and *Poa* spp. (Rey et al. 2007). The large mammal community also includes prey species such as wild boar (*Sus scrofa*), roe deer (*Capreolus capreolus*) and red deer (*Cervus elaphus*). Top predators such as wolf (*Canis lupus*) and the Eurasian lynx (*Lynx lynx*), have also a permanent presence in the study area.

Telemetry data

To evaluate the spatial ecology of brown bears, we captured 13 individuals using a bespoke 7.5 m^3 cuboid cage with two independent gliding doors. Bears were captured between 2011–2014 (April–September) in 13 locations (Table 1). All field procedures and the immobilisation of the bears were made under veterinary supervision and carried out in accordance with verified protocols (www.carnivoremari.ro). Bears were tranquilised using medetomidine–zolazepam–tiletamine or medetomidine-ketamine drug combinations (Fahlman et al. 2011). The drugs were delivered with a gas

Table 1. GPS collared brown bears in Eastern Romanian Carpathians and Subcarpathians.

Bear code	Sex	Age class	Monitoring period	Monitoring days	Hours between fixes	No. of successful fixes
Bear2	male	subadult	2013	233	1	4836
Bear4	female	subadult	2013–2014	368	1	8413
Bear5	male	adult	2011–2012	300	1	3969
Bear6	male	adult	2011–2012	405	1	8392
Bear8	female	adult	2012–2014	738	1	12313
Bear10	male	adult	2012–2013	324	1	5646
Bear12	male	adult	2013–2014	420	1	6212
Bear13	female	subadult	2014–2015	386	2	1231
Bear14	male	subadult	2014–2015	309	2	2021
Bear15	male	adult	2014–2015	387	2	1781
Bear16	female	adult	2014–2015	360	2	1725
Bear17	male	adult	2014–2015	270	2	1024
Bear18	male	subadult	2012–2013	308	2	2444

driven rifle or with a blow pipe. The eyes were lubricated to avoid corneal abrasions or ulceration and a blindfold was placed to protect the eyes and decrease visual stimuli (West et al. 2007).

Bears were fitted with 8 GPS ProLight collars with GSM transmission (Vectronic Aerospace Gmbh) and 5 G2110 collars with Iridium transmission (Advance Telemetry System, USA). Collars were equipped with mortality sensors and with a 12 months planned drop-off activation system. The GPS collars were programmed to collect fixes between 1 to 2 hours. Data were received on a compatible GSM station or through Iridium Data Service available with the collars and pre-processed in order to remove locations with coordinates errors.

The monitoring interval for each individual varied between 233 days (Bear2, subadult male) and 738 days (Bear8, adult female) (median = 360 days, interquartile range - IQR = 387–308- days; Table 1). During the study, we collected 59997 successful fixes (median = 3969, IQR = 6107–1781). The lowest number of locations was 1024 fixes in 270 days (Bear18, male) and the largest 12313 fixes in 738 days (Bear8, female) (Table 1).

Data analysis

To analyse the seasonal variation of home ranges and daily distances covered, we divided annual data into 4 seasons (Szabo et al. 2013): Winter sleep season (season 1, 15 November – 31 March); Den exit and reproduction season (season 2, 1 April – 15 June); Forest fruits season (season 3, 16 June-31 August); and Hyperphagia season (season 4, 1 September – 14 November). The classification captures the denning period and the variation in food availability with possible influences in bear behaviour. By analysing the seasonal movements (only for bears monitored all four seasons), we expected to observe small home ranges and movements during the Winter sleep season and larger home ranges and movements during Hyperphagia.

We estimated home ranges size for each individual using the 95% minimum convex polygon (Dahle et al. 2006), hereafter MCP95% and core areas within the home range by using kernel density estimator (KDE) for 50% isopleths with reference bandwidth estimated by adehabitatHR R package (Worton 1989, Cale.g., 2006), hereafter KDE50. After partitioning data by seasons, gender and age, we tested seasonal and gender/age-specific differences in home range size using non-parametric Mann-Whitney or Kruskal-Wallis tests (Kernohan et al. 2001). We also analysed the spatial overlap between individual home ranges and the game management units limits in order to assess the suitability of the game management units size for the brown bear monitoring and management. For the home ranges-GMU spatial overlap analysis, we considered only GMUs with >5% of area overlapped with each individual home range or home range core activity areas.

Additionally, we analysed the daily displacement length (m/day) by calculating the Euclidian distance between consecutive fixes at a time interval of 24 hours. Using non-parametric Mann-Whitney test, we tested for seasonal and gender/age-specific differences in daily displacement length and for altitudinal variation between individuals during different seasons in order to test the influence of changes in vegetation distribution and phenology on individuals' movements.

For statistical analyses and graphics, we used packages adehabitatHR (Cale.g., 2006), dunn.test (Dinno 2017), maptools (Bivand 2017) and ggpubr (Kassambara 2017) for R 3.4.3 (R Core Team 2017) and ArcMET movement ecology toolbox for ArcGIS Desktop 10.3.1 (Wall 2014).

The data, underpinning the analysis reported in this paper, are deposited in the Dryad Data Repository at http://dx.doi.org/10.5061/dryad.jk127ng.

Results

Brown bear home ranges

The median of MCP95% home ranges of brown bears in Eastern Carpathians and Subcarpathians was 629.92 km^2 (IQR = 925.66–131.12). Both the largest and smallest home ranges were recorded for adult males (max = 3142.94 km^2, min = 73.35 km^2) (Figure 2). We did not find statistically significant differences between the MCP95% of males and females (Mann-Whitney W = 17, p = 0.94), but ranges varied widely for males; we did not find differences between adults and subadults (Mann-Whitney W = 14, p = 0.44), but the subadult bear movement showed higher individual variation.

The number of core activity areas, estimated using KDE50, varied between min 1 and max 4 areas (median = 2). The median size of core areas per bear was 36.37 km^2 (IQR = 84.71–11.91), with minimum and maximum recorded for adult males (min = 1.04 km^2, max = 363.81 km^2) (Figure 3).

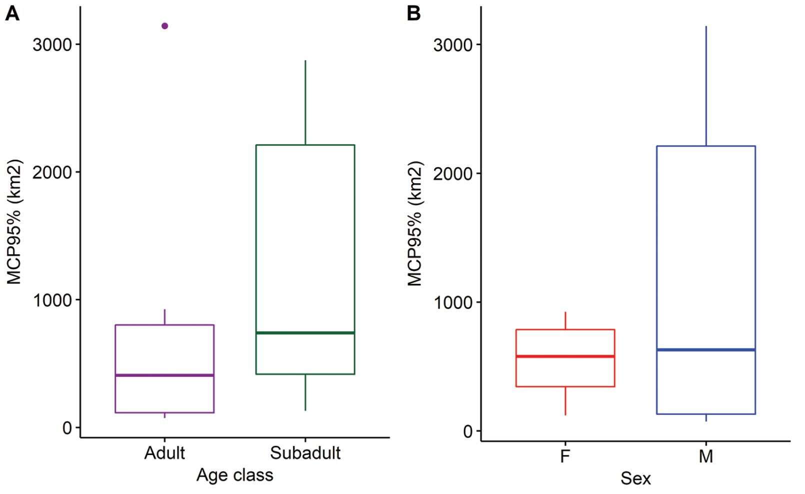

Figure 2. Brown bear home range (MCP95%) size by age class (**A**) and sex (**B**) in Eastern Romanian Carpathians and Subcarpathians (box = interquartile range, horizontal line = median, whiskers = 1.5 × interquartile range, points = outliers).

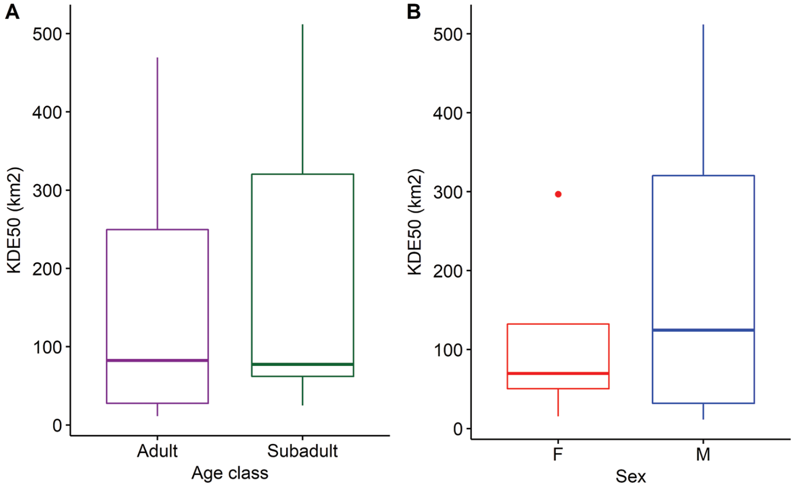

Figure 3. Core area size by age class (**A**) and sex (**B**) in Eastern Romanian Carpathians and Subcarpathians (box = interquartile range, horizontal line = median, whiskers = 1.5 × interquartile range, points = outliers).

Seasonally, the smallest MCP95% home range size (2.98 km^2) was estimated during the Winter sleep season for a subadult male and the largest home range (2036.11 km^2) during Hyperphagia season for an adult male (Table 2). Moreover, we did not record statistically significant differences between seasonal home ranges estimated using MCP95% (Kruskal-Wallis = 3.86, df = 3, p = 0.28).

Table 2. Brown bears MCP95% seasonal home range sizes in Eastern Romanian Carpathians and Subcarpathians (M = males, F = females).

Bear	Sex	Age class	MCP95% (km^2)			
			Winter sleep	Den exit and reproduction	Forest fruit season	Hyperphagia
Bear2	M	subadult	29.88	22.98	24.04	54.50
Bear4	F	subadult	2.98	6.54	425.66	69.52
Bear5	M	adult	56.95	49.79	16.71	23.89
Bear6	M	adult	344.92	54.95	109.88	854.02
Bear8	F	adult	77.30	94.59	57.87	85.71
Bear10	M	adult	27.25	115.11	188.43	113.39
Bear12	M	adult	252.72	211.75	1195.78	2036.11
Bear14	M	subadult	46.82	34.24	210.78	1222.29
Bear15	M	adult	177.14	14.36	201.84	79.06
Bear18	M	subadult	7.76	1561.42	3.03	1047.06
Median			51.88	52.37	149.155	99.55
IQR			152.18–27.90	109.98–25.79	208.54–32.49	998.8–71.90

Overlap between brown bears home ranges and Game Management Units

The mean size of the 272 GMUs within our study area was 126.97 km^2 (stdev = 32.56 km^2, min = 70.56 km^2, max = 294.56 km^2). The number of GMUs overlapping with MCP95% individual home ranges varied between 2 and 32 GMUs (median = 8, IQR = 17–4) with males home range size overlapping more GMUs compared to females and subadult individuals home range size overlapping more GMUs than adults (Figure 4).

The number of GMUs overlapping with KDE50 home range core areas individual home ranges varied between 1 and 10 GMUs (median = 3, IQR = 7–2), with males overlapping more GMUs than females (Figure 5).

Brown bear daily displacement length

The mean daily displacement length calculated for brown bears with data in all seasons was 1818.78 m (stdev = 2338.29 m/day, max = 20833.7 m/day). Seasonal movement analysis indicates statistically significant differences between seasons (Kruskal-Wallis = 82.87, df = 3, $p < 0.001$), i.e., between Winter sleep season and all other seasons (Table 3). The most active season in terms of daily displacement length was the Hyperphagia (Figure 6) with a mean value of 2097 m (stdev = 2855.72). The Den exit and reproduction season is also an active season for bears, with an average daily displacement length of 1884 m (stdev = 2257.21). The mean daily distances estimated during Forest fruits season (1842 m, stdev = 1917.60) and Winter sleep (1274 m, stdev = 1848.58) are lowest. The GPS-collared brown bears travelled between a minimum altitude of ~234 m and a maximum of ~1634 m. The average altitude of locations was ~886 m (stdev

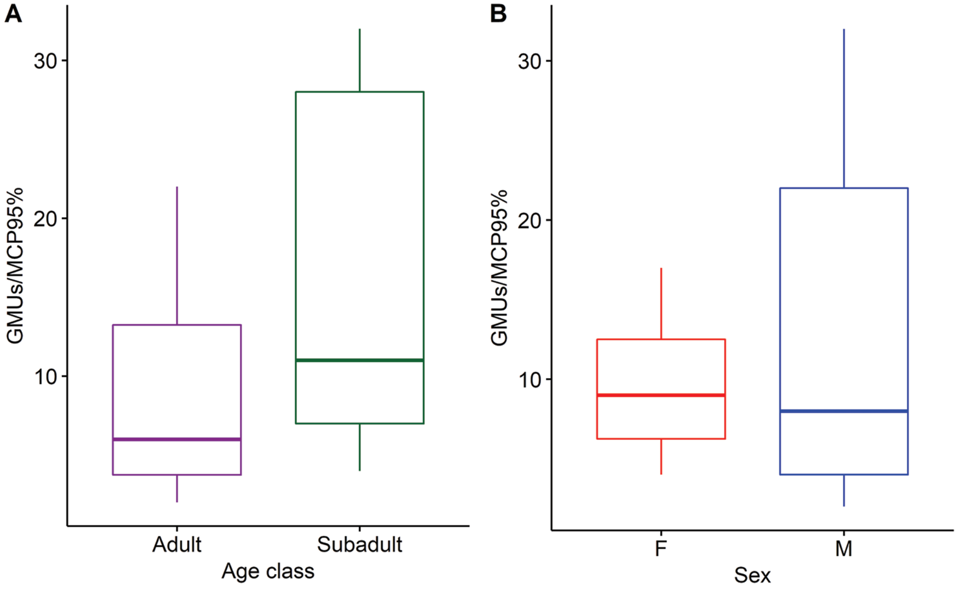

Figure 4. Number of Game Management Units (GMUs) overlaping subadults/adults bears (**A**) and females/males (**B**) MCP95% annual home ranges in Eastern Romanian Carpathians and Subcarpathians (box = interquartile range, horizontal line = median, whiskers = 1.5 × interquartile range).

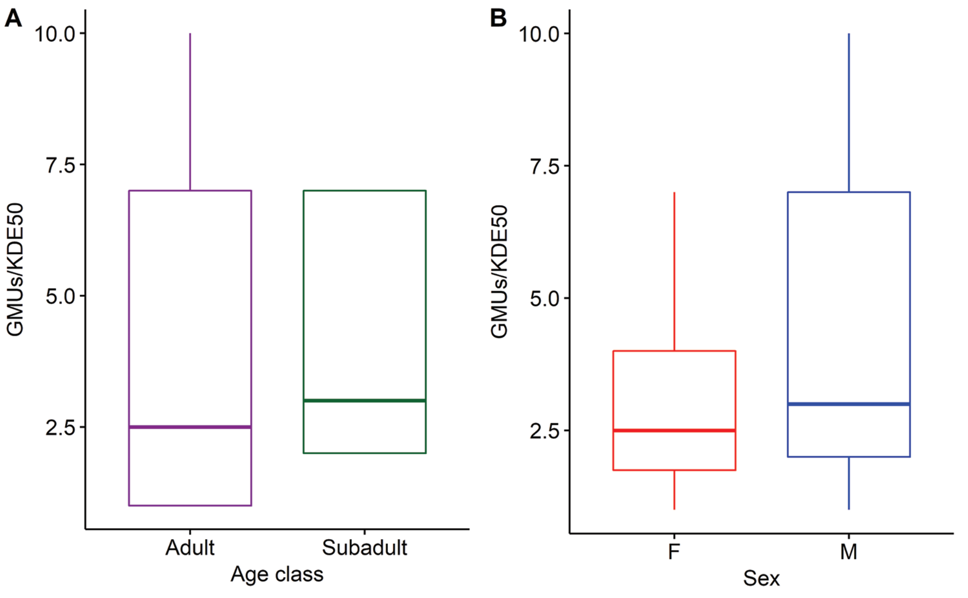

Figure 5. Number of Game Management Units (GMUs) overlaping subadult/adult brown bears (**A**) and females/males (**B**) core areas (KDE50) in Eastern Romanian Carpathians and Subcarpathians (box = interquartile range, horizontal line = median, whiskers = 1.5 × interquartile range).

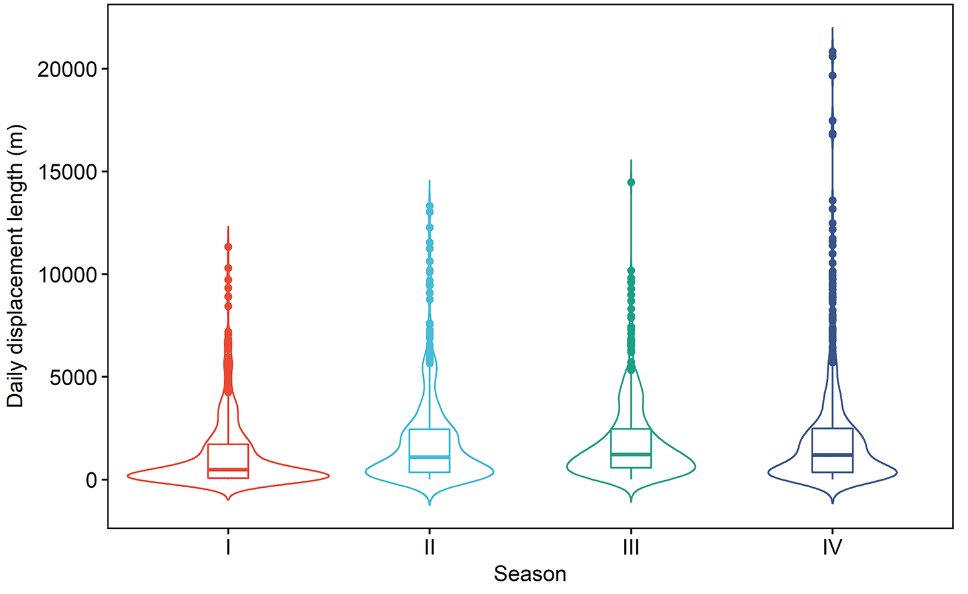

Figure 6. Seasonal variation of the mean daily displacement length of brown bear in Eastern Romanian Carpathians and Subcarpathians : I – Winter sleep ; II – Den exit and reproduction ; III – Forest fruits; IV – Hyperphagia. (Horizontal line = median value, box = interquartile range, the vertical width = density of the data within a season, points = outliers).

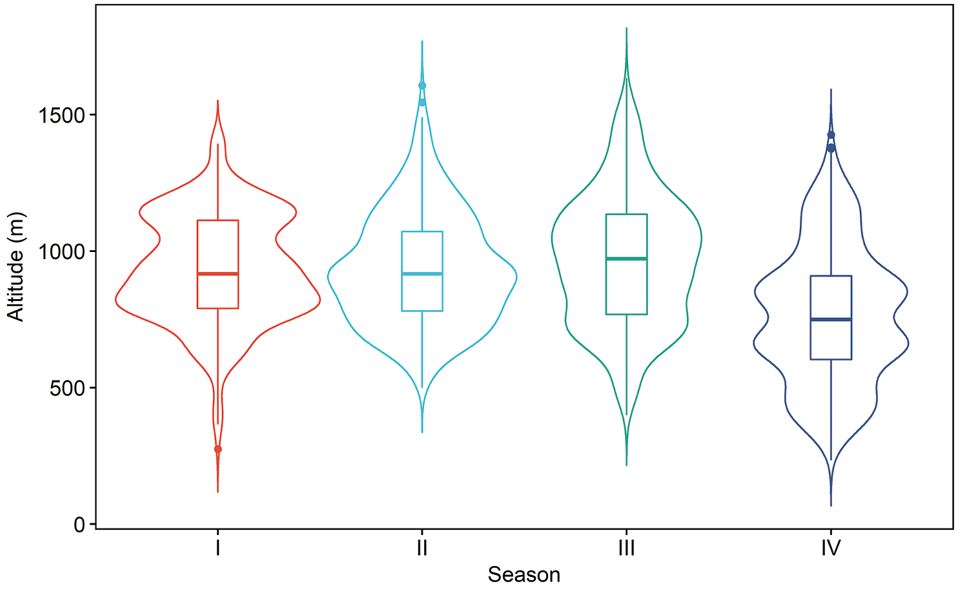

Figure 7. Seasonal variation of the altitude of brown bear locations in Eastern Romanian Carpathians and Subcarpathians: I – Winter sleep ; II – Den exit and reproduction ; III – Forest fruits ; IV – Hyperphagia. (Horizontal line = median value, box = interquartile range, the vertical width = density of the data within a season, points = outliers.

= 242.56), while the mean altitudes of locations by seasons were: ~933 m for Winter sleep (stdev = 196.35); ~932 m for Den exit and reproduction (stdev = 204.86); ~968 m for Forest fruit (stdev = 239.12); and ~761 m for Hyperphagia (stdev = 246.27). The season with the lowest recorded altitude (234 m) was Hyperphagia and the season with the highest recorded altitude was the season of Winter sleep (1634 m) (Figure 7). The Kruskal-Wallis test indicates statistically significant differences between the altitude occupied by brown bears in the four seasons (Kruskal-Wallis = 252.03, df = 3, $p < 0.001$), i.e., between the Hyperphagia season and all other seasons (Table 4).

Table 3. Comparison of seasonal daily displacement length of brown bears in Eastern Romanian Carpathians and Subcarpathians (Dunn test with Bonferroni adjustment, $\alpha = 0.05$).

Season	Winter sleep	Den exit and reproduction	Forest fruits
Den exit and reproduction	W = -6.51, p < 0.001	–	–
Forest fruits	W = -8.35, p < 0.001	W = -1.61, p = 0.32	–
Hyperphagia	W = -7.64, p < 0.001	W = -0.53, p = 1.00	W = 1.28, p = 0.66

Table 4. Comparison of seasonal altitude of brown bears GPS fixes in Eastern Romanian Carpathians and Subcarpathians (Dunn test with Bonferroni adjustment, $\alpha = 0.05$).

Season	Winter sleep	Den exit and reproduction	Forest fruits
Den exit and reproduction	W = 0.51, p = 1.00	–	–
Forest fruits	W = -1.61, p = 0.32	W = -2.17, p = 0.09	–
Hyperphagia	W = 11.40, p < 0.001	W = 11.39, p < 0.001	W = 13.99, p = < 0.001

Discussion

Our analysis of brown bear movement and space use from GPS telemetry data showed that previous predictions on bear movement ecology and home range sizes from the Romanian Carpathians (e.g., Comsia 1961, Maanen et al. 2002) were not realistic. The estimated median MCP95% home range (~630 km^2) and median home range core areas (~36 km^2) were more than three times larger than published information. Furthermore, our estimated home range size was higher than brown bear home ranges in the Northern or Southern Europe (Dahle and Swenson 2003, Dahle et al. 2006, Gavrilov et al. 2015). Individual seasonal home ranges varied from a few square kilometres to over 2000 km^2 (see Table 3) and, for the Hyperphagia season, home ranges had larger values (see Figure 3), although we did not detect significant differences between seasons. Our results also show that there are no differences between age groups or between males and females, which contradicts findings from other European studies (Dahle and Swenson 2003). However, we did detect higher variation in home range size for males and subadults.

The number of core areas identified for each bear varied between 1 to 4, while the median area of activity centres (KDE50) was estimated at under 40 km^2, demonstrating that bears may intensively use several areas during a year and such areas can be larger than a GMU. The median number of 8 GMUs overlapping with individual home ranges (MCP95% home ranges) and 3 GMUs overlapping with home range core areas (KDE50 core areas), suggest that the size of GMUs in our study area (mean = 126.97 km^2) might not be suitable for planning bear management and especially as a population census base unit, as done presently. Thus, GMUs as sampling units might be a biased approach that can lead to poor management decisions at the population level, such as overharvesting (Popescu et al. 2016) or unnecessary supplementary feeding (Selva et al. 2017). Planning further census techniques should consider that male home ranges overlap more GMUs than those of the females (see Figures 4 and 5), mostly as a result of the brown bear mating system (Dahle and Swenson 2003).

This study presents the first extensive assessment of space use and movements for brown bears in the Romanian Carpathians. Our results show larger home range size in Romania compared to bears in Bulgaria (MCP100% and Kernel 99% isopleth for home ranges and Kernel 50% isopleth for core areas, Gavrilov et al. 2015) and Sweden (MCP95%, Dahle et al. 2006) and comparable to those reported in Italy (MCP100% and Kernel 95% isopleth for home ranges and Kernel 50% isopleths for core areas, Preatoni et al. 2005). The larger home range sizes from our study could be due to external factors such as human disturbances due to logging activities, heterogeneous landscapes or food availability. In particular, the home range sizes may have been influenced by the presence of supplementary feeding locations (3–5/100 km^2 in study area, personal estimation). Bear daily displacement length comparisons revealed minor differences between seasonal movements: the Winter season displacement distances were smaller compared to the Hyperphagia season (Figure 6). The daily mean distance, estimated in our case, corroborates those obtained in other studies – median daily distance of 1500 m in Croatia (Huber and Roth 1993) and averaged 2450 m in Greece (Mertzanis et al. 2005).

Seasonally, Hyperphagia resulted in increased home ranges and daily movements in all individuals. During the Hyperphagia season, we recorded the lowest altitude for an adult female and a highest variability of altitude between individuals, showing a tendency to seek out food resources in different types of habitats varying along an altitudinal gradient (Pop et al. 2018). Considering both the daily movement and altitude results, we observed a variability of the daily, seasonal and altitudinal movements of brown bears on relation to the seasonal and altitudinal natural food resource availability. The greater anthropogenic food availability at lower altitudes, such as orchards or crops, might also influence the brown bear distribution (Pop et al. 2012), especially during the Hyperphagia season. Seasonal movements of brown bear in the Carpathians should be analysed in relation to seasonal changes in bear diet, approach often addressed in other studies (Stofik et al. 2013, Ciucci et al. 2014) to explain changes in brown bear movements.

As the main limitation of the study was related to the small numbers of bear females (4) and subadults (5), some of our results should therefore be interpreted with caution (Preatoni et al. 2005). Using a larger dataset and considering the seasonal and altitudinal gradient of the food availability (Roellig et al. 2014), may result in differences between seasonal movements and/or between genders. Future brown bear spatial ecology studies in the Romanian Carpathians should consider both external (e.g., food availability, predation risks, presence of mating partners) and internal factors (e.g., health, age, reproductive stage) (Nathan et al. 2008, Martin et al. 2013) recommended using a landscape approach (Di Minin et al. 2016).

In summary, our study, using GPS telemetry, highlights the complex spatial ecology of the brown bear in the Carpathians, with home range sizes larger than those estimated in other European brown bear populations and daily movements that vary by season and within a broad altitude range. Human disturbance caused by traditional activities such as logging, hunting, agriculture, could not be considered when describing the movements, but it represents a key factor influencing brown bear movement and habitat selection (Martin et al. 2010), and should be considered in further studies. Notably, our study supports the implementation of brown bear monitoring at a regional scale, rather than focusing on GMUs as the monitoring unit (Popescu et al. 2016). As brown bears may use multiple GMUs annually or during a single season, a regional approach to monitoring based on remote cameras and track counts (Popescu et al. 2017) or non-invasive DNA techniques (Proctor et al. 2010) is likely to yield better results and will require coordination between multiple adjacent GMUs. Additionally, conservation initiatives should cover large areas, which seems to be difficult in Romania given the tendency of conservationists to work at a local scale (Nita et al. 2016). This study provides important information for future brown bear research and conservation, such as habitat selection studies, habitat connectivity and population estimates for Romania's brown bear population.

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