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Research article

PROOFS

Den use in captivity: insight from two brown bears

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Abstract: Understanding whether captive brown bears (*Ursus arctos*) retain natural denning and social behaviours is important for evaluating welfare and informing evidence-based husbandry practices. Here, we investigated the behaviour, den use, and social interactions of two captive brown bears, a male (Kostadin) and a female (Berna), housed together at the Nature and Animal Conservation Centre (Zoo Centre), Dobrich, Bulgaria, during two consecutive winter seasons (2022/2023 and 2023/2024). Behavioural observations were conducted using camera traps installed at den entrances. Behavioural patterns observed during the denning period were broadly consistent with those described for wild brown bears, despite lifelong captivity. Both bears exhibited markedly reduced activity during December and January. Despite the availability of an artificial bunker, both individuals excavated and used self-constructed dens. Significant individual differences in behaviour were identified. The female displayed significantly higher frequencies of den entering and leaving behaviours, whereas the male more frequently remained near the den, particularly by lying close to and sniffing the den entrance. Social behaviour also differed between individuals: the male exhibited relatively more amicable behaviours, whereas the female exhibited more agonistic ones. Nevertheless, overt aggressive interactions occurred infrequently. These findings suggest that providing captive brown bears with spacious, naturalistic enclosures, suitable substrates for digging, and seasonal husbandry practices that minimise visitor disturbance and allow feeding to be suspended can promote the expression of natural denning behaviour and provide practical opportunities to improve welfare in captivity.

Keywords: behaviour, hibernation, *Ursus arctos*, welfare, zoo

Introduction

The brown bear (*Ursus arctos* Linnaeus, 1758) is an important component of forest ecosystems in Bulgaria, where it primarily inhabits broadleaf and mixed forests in the major mountain ranges, including the Rila, Pirin, Rhodopes, and Central Balkan Mountains (Dutsov et al., 2012). Although globally classified as Least Concern by the IUCN, the Bulgarian population has declined in recent decades, with major threats including poaching, habitat fragmentation, anthropogenic disturbance, and climate change (Spiridonov & Spassov, 2015; Serbezov & Spassov, 2023). Since Balkan populations contribute substantially to the ge-

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netic diversity of European brown bears, conservation of the species in the region is of particular importance.

Hibernation is a key physiological and behavioural adaptation in brown bears that enables survival during unfavourable winter conditions by reducing metabolic activity and energy expenditure. The onset and duration of hibernation are influenced by multiple environmental factors, including temperature, latitude, and food availability (González-Bernardo et al., 2020a). In Bulgaria, winter dormancy typically begins between November and January (Todorov et al., 2020). In this regard, denning behaviour represents an essential component of hibernation ecology. Brown bear dens are typically located in inaccessible areas and may consist of natural caves, rock shelters, or excavated structures lined with plant material (Dutsov et al., 2012). Structurally, dens generally include an entrance, tunnel, and internal chamber (González-Bernardo et al., 2020a). Den occupancy and hibernation duration vary according to sex, age, reproductive status, and body condition, with males frequently leaving dens earlier than females or remaining partially active during winter (Manchi & Swenson, 2005). Anthropogenic disturbance represents a particularly important factor during hibernation, as human activity may induce premature den abandonment, increasing energetic costs and reproductive risks, especially in females with cubs (Swenson et al., 1997; Linnell et al., 2000). Because of the elusive nature of brown bears and the difficulty of direct observation in wild populations, studies of captive individuals provide valuable opportunities to examine behavioural patterns and individual differences related to den construction and use under controlled conditions.

In Bulgaria, 32 brown bears are housed in 11 zoos (Zareva-Simeonova et al., 2022). Zoo environments allow long-term behavioural monitoring, including during the denning period, and may provide insight into behavioural flexibility and welfare-related responses (Fernandez et al., 2020).

Brown bears possess high cognitive abilities and complex behavioural requirements (Vonk & Beran, 2012), which require captive management to facilitate the expression of species-typical behaviours, including foraging, denning, marking, environmental exploration, and hibernation (Gardocka et al., 2014). Hibernation is an important indicator of welfare in captive bears (Maher et al., 2021). Despite its importance for brown bear physiology and welfare, den use and den-related behaviour in captive individuals remain insufficiently studied. Therefore, the present study aimed to investigate den use in two captive brown bears during the winter period, with particular emphasis on den entry and exit patterns, den occupancy duration, behavioural activity, social interactions, and individual differences associated with hibernation behaviour. Although previous studies on captive individuals have reported only partially expressed lethargic states rather than complete hibernation, particularly under conditions of continuous food availability (Zareva-Simeonova et al., 2022; Dori et al., 2024), we hypothesise that behavioural patterns observed during the denning period, despite lifelong captivity, will largely show similarities to those described for wild brown bears.

Materials and methods

The study was conducted on two captive brown bears (*Ursus arctos*), a male (Kostadin) and a female (Berna), housed together at the Nature and Animal Conservation Centre (Zoo Centre), Dobrich, Bulgaria, during the denning period. The climate of Dobrich is characterised by relatively mild winters, with January typically the coldest month. Berna, was 14 years old at the time of the study and had been housed at the zoo centre since the age of eight months, having arrived from the zoo in Bern, Switzerland. Kostadin, was 13 years old and had been transferred from the Pleven Zoo approximately 11 years before the study. Kostadin had also undergone a vasectomy in 2015.

The bears were housed in the largest zoo bear enclosure on the Balkan Peninsula, with a total area exceeding 5 decares (approximately 5,000 m^2). The enclosure includes three lakes and an artificial bunker designed to provide shelter for winter dormancy. Despite the availability of this structure, both bears regularly excavated their own dens, exceeding 6 m in depth, where they hibernated.

Hibernation onset was inferred from the absence of animal activity and observations by zookeepers. When the bears were not observed for several consecutive days, this was considered an indication that hibernation had commenced, and public access to the enclosure surroundings was restricted. The enclosure area was typically closed from mid-November until mid-March. During the hibernation period, no food was provided to the bears by zoo staff. Feeding was resumed in spring, initially with plant-based food, fol-



Fig. 1. Camera trap photo showing Berna emerging from the den while Kostadin is near the den.

lowed by the gradual reintroduction of meat into the diet (fish and beef). Each bear consumed an average of approximately 5 kg of mixed food per day, with the amount increased during autumn to support the accumulation of the energy reserves required for winter. The bears were fed either in the morning, between 09:00 and 10:00 h, or in the afternoon, between 14:00 and 15:00 h.

From November to March 2022/2023 and 2023/2024, camera traps with solar panels were installed in front of each den to record the behaviour of the two bears near the dens (Fig. 1). Two Spromise S68 camera traps (24 Mpx) were positioned high on trees in front of the two monitored dens.. They recorded a 30-second video with information about the date and time, and bear behaviour in front of the den.

Data analyses

Video recordings obtained from camera traps installed in front of the dens were processed using the free software application Timelapse (v. 2.3.0.8). The software enabled the extraction of video metadata, including date and time of recording, as well as the creation of additional data fields for behavioural annotation. A total of 17,033 video clips were processed: 9,905 clips from the 2022/2023 denning period and 7,128 clips from 2023/2024. Video recordings showing bears at or near the den entrances were selected for behavioural assessment, resulting in 2,437 behavioural records included in the frequency analyses. For each video clip, the following variables were recorded: , date and time, individual identity, and the behaviour displayed by the observed bear.

Statistical analysis

To investigate differences in the behavioural patterns of the two individual bears, the frequency distributions of behavioural categories and their constituent sub-categories were compared using the G-test of independence (likelihood-ratio test) for contingency tables (R × C). This test evaluates whether the distribution of behavioural observations across categories is independent of individual identity by comparing observed frequencies with those expected under the null hypothesis of independence. Unlike the Pearson chi-square test, which is based on squared differences between observed and expected frequencies, the G-test uses likelihood ratios to quantify the discrepancy between these frequencies. When the overall test indicated a statistically significant association between individual identity and behavioural category, post hoc pairwise comparisons were performed to identify the categories contributing to the observed differences. The resulting p-values were adjusted using the Holm–Bonferroni method to control for false-positive results

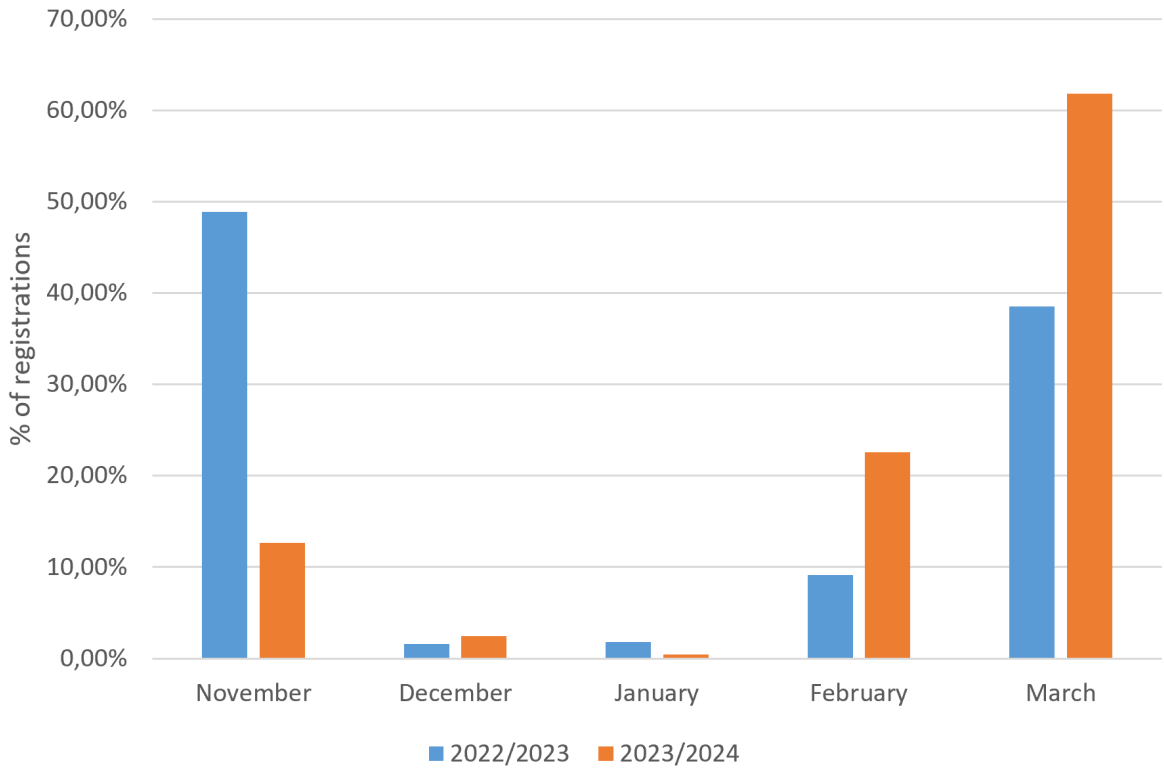

Fig. 2. Monthly occurrence of the bears at den entrances from November to March during the 2022/2023 and 2023/2024 denning periods.



Fig. 3. The female bear emerging from the den in February.

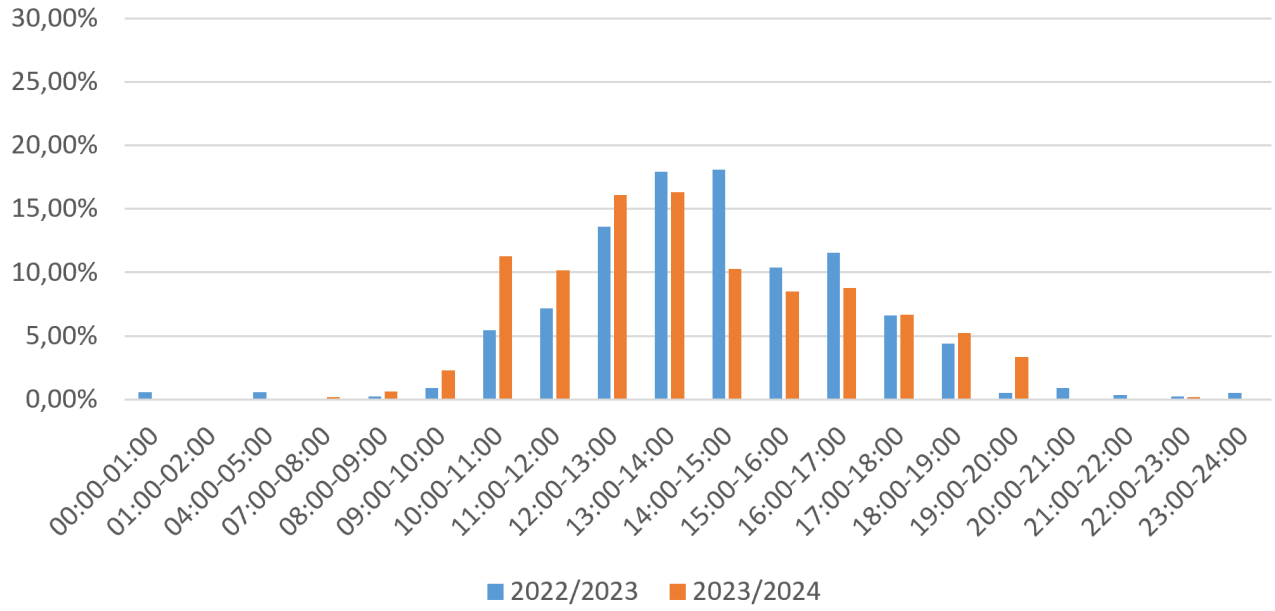

Fig. 4. Hourly distribution of brown bear registrations recorded by camera traps during the 2022/2023 and 2023/2024 denning periods.

while providing greater statistical power than the conventional Bonferroni correction. Sub-categories containing zero values were excluded from the analysis to enable assessment of statistically significant differences among the remaining ones. Specifically, two den-related sub-categories: marking the den entrance, standing near the den and looking at the den were observed exclusively in the male and were therefore excluded from the comparative statistical analysis. Significant pairwise differences were identified at $p < 0.05$. Statistical analyses were conducted in the R statistical environment using the RVAideMemoire package (Herve, 2011).

Results

Monthly activity of bears

During December and January, the activity of both bears, defined by the number of registrations, was markedly reduced (Fig. 2). Only occasional den emergence events were recorded during this period. In the winter of 2023/2024, the male was observed only once, whereas the female was not recorded outside the den. During the corresponding period of the previous year, Kostadin and Berna were captured by camera traps on nine days in December and only five days in January. Bear activity began to increase again in February and reached its highest level in March during the 2023/2024 observation period (Fig. 3).

A change in the usage dynamics of the two dens was observed over the two years. In 2022/2023, the female bear was recorded less frequently near the secondary den. However, in 2023/2024, her activity around that den significantly increased. During December and January, when the bears are least active, they were not observed together at all. Their activity was mainly diurnal from 10 am to 7 pm, with only a few registrations during the night (Fig. 4).

Behaviour

During the observation, the bears exhibited various individual and social behaviours in the area around the dens- locomotion (walking around), exploratory behaviour (looking around, sniffing around), feeding behaviour (eating, foraging, grazing), comfort behaviour (sitting, lying, bathing), and social behaviour (amicable and agonistic) (Table 1).

Some behaviours, such as vocalisation, marking, bathing, and playing (with a log), were displayed only by the male.

Table 1. Behaviours displayed by the bears in the area around the dens.

Behavioural category		**Behaviour**
Individual	Feeding	Foraging
		Chewing
		Grazing
	Resting	Lying on the ground
		Sitting
		Standing
	Locomotion	Walking around
		Running
	Exploratory	looking/sniffing around while standing
		looking/sniffing around while walking
	Den-related behaviours	Collecting bedding
		Entering the den
		Leaving the den
		Lying near the den
		Marking the den entrance
		Sitting near the den
		Sniffing around the den
		Sniffing the den entrance
		Standing near the den and looking at the den
Social	Agonistic	Attack
		Chasing
		Fighting
		Gaping
		Fleeing
		Retreat
	Amicable	Following
		Sniffing (head/body)
		Grooming
		Allogrooming
		Standing next to each other

Individual behaviour: feeding, resting, locomotion, exploratory

The overall distribution of individual behaviours differed significantly between the studied animals (G = 527.54, df = 16, $p < 0.001$), indicating marked variation in behavioural frequencies across categories. When grouped into behavioural categories, significant differences were also observed (G = 173.90, df = 4, $p < 0.001$). Holm-adjusted post hoc comparisons showed significant differences between exploratory and locomotory behaviours ($p < 0.001$), exploratory and resting behaviours ($p < 0.001$), exploratory and feeding behaviours ($p < 0.001$), as well as between locomotion and resting ($p < 0.001$), locomotion and feeding ($p < 0.001$), and

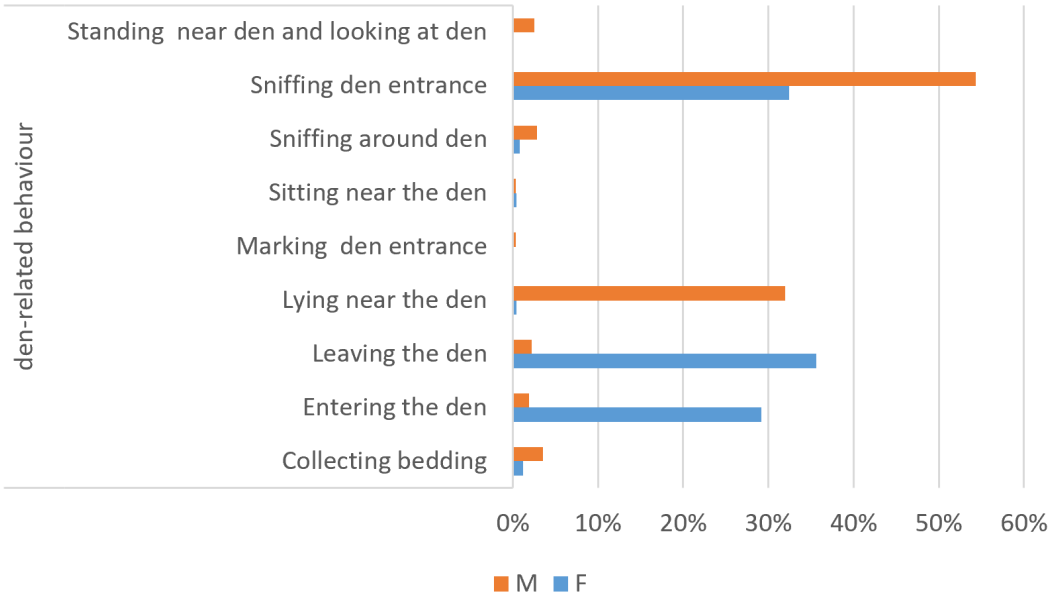

Fig. 5. Den-related behaviours by the male and female bears.

resting and feeding (p = 0.002). Den-related behaviours differed significantly from locomotion, resting, and feeding categories (all $p < 0.001$), whereas no difference was detected between den-related and exploratory behaviours (p = 0.103). Exploratory behaviours occurred similarly in both individuals, whereas locomotory, resting, and feeding behaviours were more frequently expressed by the male.

Significant differences were also found in individual behaviours unrelated to den activity (G = 182.43, df = 9, $p < 0.001$). Holm-adjusted post hoc analysis showed significant differences between walking around and exploratory behaviours (both $p < 0.001$), lying on the ground and exploratory behaviours (both $p < 0.001$), as well as between grazing and multiple behavioural categories, including exploratory behaviours, walking around, standing, and foraging (all $p < 0.001$). The male bear expressed locomotory, resting, and grazing-related behaviours more frequently than the female.

Individual behaviour: den-related

Analysis restricted to den-related behaviours revealed significant differences in behavioural distribution (G = 315.46, df = 6, $p < 0.001$). Post-hoc pairwise comparisons revealed significant differences among several behaviours– collecting bedding differed significantly from entering the den ($p < 0.001$), leaving the den ($p < 0.001$), and lying near the den (p = 0.03). The frequency of entering the den differed significantly from lying near the den, sniffing around the den, and sniffing the den entrance (all $p < 0.001$). Similarly, leaving the den differed significantly from lying near the den, sniffing around the den, and sniffing the den entrance (all $p < 0.001$). Significant differences were also detected between lying near the den and both sniffing around the den ($p < 0.001$) and sniffing the den entrance ($p < 0.001$), as well as between sitting near the den and sniffing the den entrance ($p < 0.001$).Behaviourally, the female was characterised by more frequent den entering and leaving, whereas the male more commonly exhibited behaviours associated with den proximity, including lying near and sniffing the den entrance (Fig. 5).

Social behaviour

There were significant differences in the frequencies across categories of the males' and the females' social behaviour (G = 26.61, df = 10, p = 0.003), indicating differences in behavioural allocation between individuals. When social interactions were grouped into ami-

cable and agonistic categories, a significant difference in behavioural distribution was also observed (G = 9.46, df = 1, p = 0.002), with the male exhibiting proportionally more amicable behaviours and the female showing a higher occurrence of agonistic interactions. Holm-adjusted post hoc comparisons revealed that the following, which were more frequently expressed by the male, differed significantly from chasing (p = 0.03), fleeing (p = 0.045), retreat (p = 0.01), more frequently expressed by the female and sniffing (p = 0.01), with the highest frequency in both sexes. In contrast, no significant differences were identified among the remaining social behaviours.

Discussion

The markedly reduced activity of both brown bears during December and January corresponds with the reported hibernation period of wild brown bears in Bulgaria, supporting the view that captive individuals maintained under appropriate environmental conditions may preserve seasonally adaptive behavioural patterns. Previous studies have suggested that continuous food availability may result in only partially expressed lethargic states in captive brown bears, whereas withholding food during the winter period may promote more complete hibernation (Zareva-Simeonova et al., 2022; Dori et al., 2024). In the present study, feeding was suspended during the denning period, and both bears exhibited a marked seasonal reduction in activity. Increased activity observed from February onwards, reaching a maximum in March, likely reflects the transition out of hibernation, consistent with previous findings describing emergence from dens and increased movement during late winter and early spring (Evans et al., 2016). Earlier den emergence has also been associated with higher spring temperatures, and ongoing climate warming may contribute to shifts towards earlier den exit in brown bears (González-Bernardo et al., 2020b). At the same time, the housing conditions at the Nature and Animal Conservation Centre may have facilitated the expression of biologically relevant denning behaviour. Although an artificial bunker was available, both individuals excavated their own dens, suggesting behavioural flexibility and maintenance of species-typical denning behaviour. Human disturbance, recognised as one of the principal causes of den abandonment in wild brown bears (Swenson et al., 1997), was minimised because visitor access was restricted after zookeepers identified the onset of hibernation and feeding was discontinued during the winter period. These management conditions may have supported the expression of seasonal denning behaviour, highlighting the importance of appropriate environmental and husbandry conditions related to the welfare of captive brown bears. Despite similarities with wild conspecifics, diel activity patterns differed from those commonly described in free-ranging brown bears. Kostadin and Berna were predominantly active during daylight hours, particularly between 10:00 and 19:00 h, whereas wild brown bears are generally crepuscular and frequently increase activity during early morning and evening hours (Donatelli et al., 2022). However, diurnal activity has been documented in areas with limited anthropogenic disturbance (Klinka & Reimchen, 2002). It can be assumed that in the present study, daytime activity peaks reflect predictable feeding schedules in captivity, particularly because behavioural activity increased during afternoon hours when food provisioning was anticipated.

Clear individual differences in den use and den-related behaviours were observed. The female displayed significantly higher frequencies of den entering and leaving behaviours, whereas the male more frequently remained in close proximity to the den, including lying near and sniffing the entrance. These differences may reflect individual behavioural strategies associated with denning. Female brown bears typically spend longer periods in dens and show greater den fidelity, whereas males often emerge earlier and may remain more active during winter (Manchi & Swenson, 2005). Thus, the observed differences are compatible with previously described sex-related patterns but should be interpreted as individual-level observations because of the small sample size, rather than generalised to the species (Kuhar, 2006). In the present study, Berna changed den preference between years, spending longer periods in the main den during 2022/2023 but favouring a secondary den during 2023/2024, while Kostadin showed no consistent den preference. Moreover, during the second observation period, the male was rarely recorded entering the two monitored dens, which may suggest that he used temporary resting sites or an unrecorded den elsewhere within the enclosure. However, this interpretation remains

speculative and would require additional monitoring for confirmation.

The behavioural repertoire observed in both individuals suggests the retention of numerous species-specific behaviours despite lifelong captivity. Locomotory and exploratory behaviours represented the dominant behavioural categories, consistent with the ecology of wild brown bears, which naturally occupy extensive home ranges and invest considerable time in movement and environmental exploration while searching for food. Walking around represented the most frequently expressed individual behaviour, particularly in the male, while exploratory sniffing and environmental investigation occurred at comparable frequencies in both bears. The large enclosure area, natural substrate, and vegetation likely promoted behavioural opportunities for locomotion, grazing, digging, and environmental investigation. Resting behaviours, particularly lying on the ground, and feeding-related activities such as grazing were more frequently expressed by the male, possibly reflecting individual variation in activity budgets or behavioural allocation during the denning period.

Social interactions between individuals also demonstrated individual differences. Although agonistic and amicable interactions occurred at relatively low frequencies, the male more commonly displayed amicable social behaviour, particularly following, whereas the female showed a higher occurrence of agonistic interactions, including chasing, fleeing, and retreat. These findings may indicate behavioural asymmetry within the dyad, in which the male more frequently initiated affiliative proximity while the female more often regulated social distance. However, this interpretation should be treated with caution, because causal relationship between the behaviours of the two individuals was not analysed in this study. At the same time, the generally low occurrence of aggressive interactions and the rarity of fighting suggest stable social coexistence between the two captive bears. Social vocalisation and den-marking behaviour were observed only in the male, potentially indicating sex-specific communication or territorial signalling, although conclusions remain limited because of the low frequency of these events.

Taken together, the findings indicate that, despite lifelong captivity, both bears expressed a broad range of behaviours characteristic of wild brown bears during the denning period. The provision of suitable environmental conditions, including access to naturalistic denning opportunities, reduced anthropogenic disturbance, and management practices aligned with biological requirements, may support the expression of species-typical behaviours and contribute to good welfare in captivity.

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Conflicts of interest

No potential conflict of interest has been reported by the authors, reviewers, or subject editor.

Author' contributions

(using CrediT)

Venislava Spasova: conceptualisation, data curation, methodology, project administration, writing—original draft; Danita Nikolova: data curation, investigation, writing—original draft; Rumyana Kostova: formal analysis, validation; Daniela Simeonovska-Nikolova: methodology, validation, writing—review and editing; Katerina Zareva-Simeonova: conceptualisation, investigation; Krastio Dimitrov: data curation, investigation; Vladimir R. Todorov: project administration, writing—review and editing; Hristian Hristov: conceptualisation, data curation.

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