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Does ambient temperature affect behavioural activity prior to torpor in two captive Scandinavian brown bears (*Ursus arctos arctos*)?

A welfare assessment including diet investigation.

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Content

1 Abstract

Brown bears (*Ursus arctos*) occupy various habitats resulting in many subspecies with differing living conditions and diets. The Scandinavian brown bear (*U. arctos arctos*) has a mixed diet consisting of meat, fish, berries etc. While preparing for torpor in autumn, their diet consists of up to 80% berries and individuals have been observed to actively ignore fresh fish to consume berries instead. Wild bears are also shown to adjust their behavioural activity to the ambient temperature, leading to lower activity during low temperatures and vice versa. Since little is known about the pre-torpor behaviours of captive brown bears, this project researched the behavioural activity of two brown bears at Kolmården Zoo in Sweden. The hypotheses were that the behavioural activity would correlate with the ambient temperature and that behavioural activity would decrease close to torpor. The zoo-diet was also investigated through literature research. The bears were out of sight more than half of the observation time. Also, there was no significant correlation between behavioural activity and ambient temperature. Behavioural activity differed significantly between months, where the intact bear's behavioural activity decreased close to torpor, while the castrated bear showed the opposite. Possible effects of castration and dietary lipids are discussed, as well as welfare improvements. Since a lot of observation time was lost, a bigger dataset would enable a larger sample size and therefore more reliable results regarding captive brown bears' behavioural activity patterns.

Keywords: Activity patterns, ambient temperature, behavioural activity, behavioural observation, castrated, dietary lipids, intact torpor, *Ursus arctos arctos*

2 Introduction

Bears belong to the family tree of *Ursidae*, where the first divisions are the subfamilies of *Ailuropodinae* (Giant pandas), *Tremarctinae* (Spectacled bears) and *Ursinae* (sloth, sun, black, polar and brown bears; Figure 1). It has proven difficult to find the exact phylogenetic relationships regarding different bear species (Pages et al., 2008; Yu et al., 2004; Talbot & Shields, 1996), hence, the subfamily *Ursinae* is still debated.

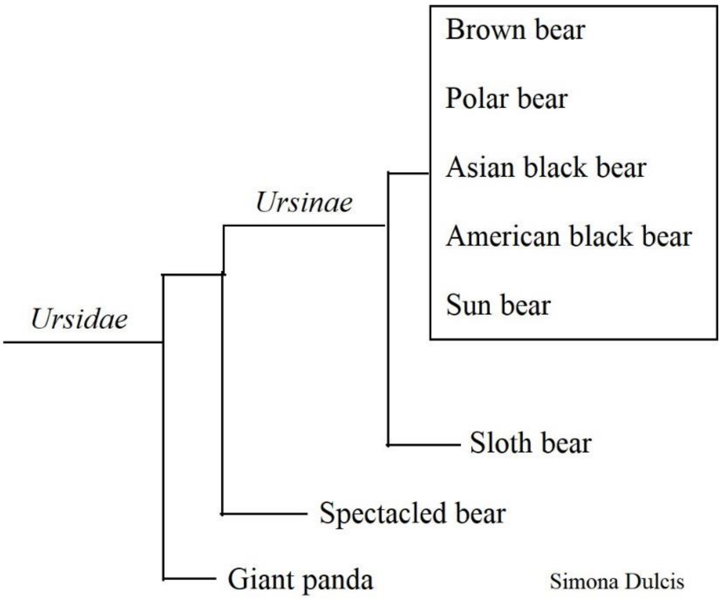

Figure 1: The family tree of bears. The exact phylogenetic relationships of Ursinae (box) are still debated.

2.1 The brown bear

The brown bear (*Ursus arctos*) is, like many other bears, a top predator that occupies various habitat types, from dry deserts to arctic tundra. Wild brown bears are distributed in North America, Europe and Asia (Swenson et al., 2000). There are several subspecies of the brown bear, including the rare Gobi bear (*U. arctos gobiensis*; Figure 2a), the Tibetan brown bear (*U. arctos pruinosus*; Figure 2b), the Grizzly bear (*U. arctos horribilis*; Figure 2c), the Kodiak bear (*U. arctos middendorffi*; Figure 2d) and the Scandinavian brown bear (*U. arctos arctos*; Figure 2e; Thiel et al., 2022; Davaasuren et al., 2022; Haroldson et al., 2021; Dai et al ., 2020) to mention a few.

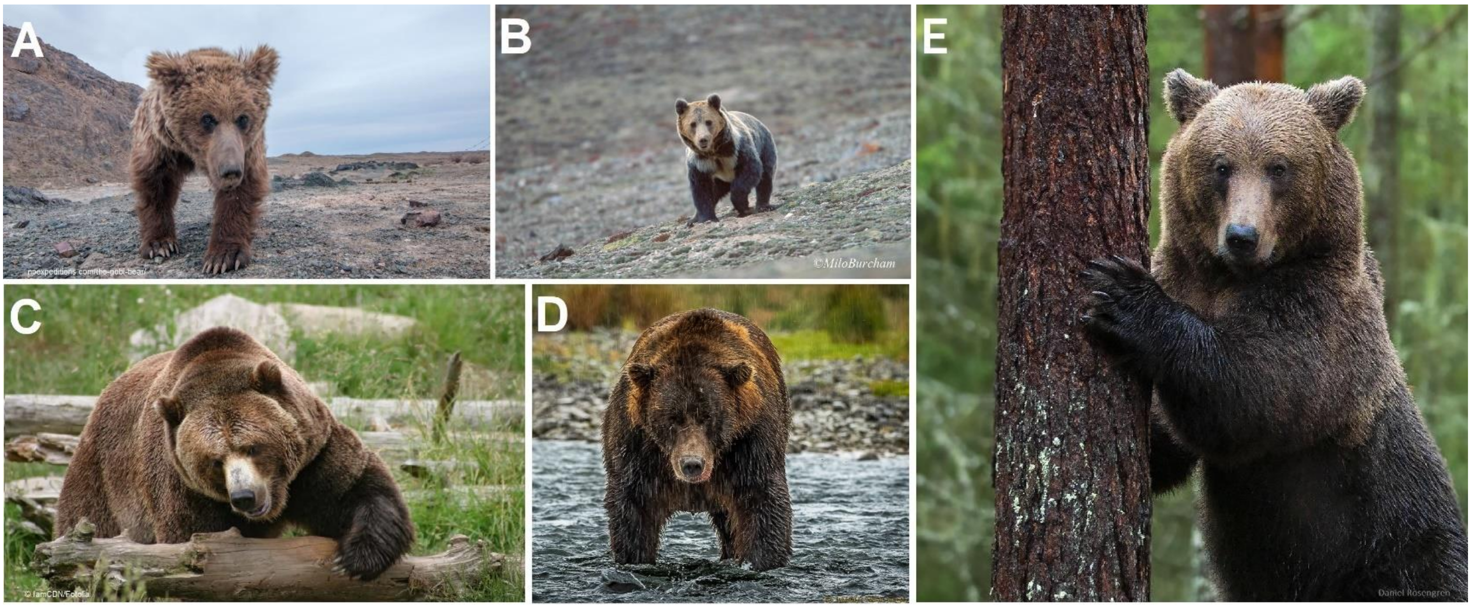

Figure 1: Five subspecies of the brown bear, (A) the Gobi bear (U. a. gobinensis), (B) the Tibetan brown bear (U. a. pruinosus), (C) the Grizzly bear (U. a. horribilis), (D) the Kodiak bear (U. a. middendorffi) and (E) the Scandinavian brown bear (U. arctos arctos).
The pictures were obtained 2023-07-03 at (A) https://npexpedition.com/the-gobi-bear/, (B) https://www.milosphotos.com/G_TibetanPlateau/index.htm, (C) https://www.britannica.com/animal/grizzly-bear, (D) https://eswildlifephotoimages.ca/wildlifer-journal/erics-alaskan-adventure and (E) 2024-05-09 at https://danielrosengren.se/bears-in-sweden/

Depending on climate and location, bears have different challenges to face. Low ambient temperatures often result in low food abundance and there are different ways of coping with those external circumstances. Bears are often mistakenly associated with a behaviour called *hibernation* (González-Bernardo et al., 2020), which is an occurrence where the body temperature approaches ambient temperature (below 10 °C) and the metabolic rate drops (Smith & Smith, 2015). Even if the metabolic rate of bears can decrease to a similar level as of small hibernators, the body temperature only decreases 2-5 degrees °C (Giroud et al., 2019), which is why the winter-sleeping strategy of bears is not considered as hibernation (Hickman et al., 2017; Smith & Smith, 2015).

The behaviour of bears sleeping and staying inactive during winter is called different things depending on literature. Even if physiologically inaccurate, “hibernation” is widely used (Thiel et al., 2022; González-Bernando et al., 2020; Giroud et al., 2019; Evans et al., 2016), but also “denning” (González-Bernando et al., 2020), “overwintering” (Delgado et al., 2018), “winter sleep” (Smith & Smith, 2015), “daily torpor” or “long torpor bouts” (Giroud et al., 2019; Giroud et al., 2018; Smith & Smith, 2015; Ware et al., 2012). The current study will use the term torpor, which means that an animal is behaviourally inactive (but will arouse if provoked) and is actively reducing its metabolic rate drastically followed by a small decrease in body temperature (Giroud et al., 2019; Smith & Smith, 2015).

Wild Scandinavian brown bears usually go into torpor in late October/early November and exit their dens between late March and early May (Thiel et al., 2022). Interestingly, not all brown bears torpor. Studies done on wild individuals in the south of Europe (Italy and Spain) found that some avoid it entirely (Swenson et al., 2007). Two factors affecting torpor are ambient temperatures such as a warm climate and physiological factors such as diet (Thiel et al., 2022).

2.2 Effects of Ambient Temperature on Brown Bears

Studies have found that ambient temperature has a large effect on wild brown bears' general behavioural activity (Dar et al., 2021; González-Bernardo et al., 2020; Evans et al., 2016). Swedish brown bears are active in ambient temperatures ranging between +15 and -5 °C and their activity has shown to fluctuate along with the ambient temperature, resulting in low behavioural activity during low temperatures and vice versa (Evans et al., 2016). The high temperatures in the south of Europe might explain why some brown bears stay active throughout the whole year (Swenson et al., 2007). Thus, ambient temperatures too great (far above 15 °C) can result in heat stress, leading to increased metabolic rate and decreased fitness (Dar et al., 2021). The ambient temperatures in spring and autumn have also shown to affect how early/late brown bears enter and exit their dens. Spring seasons with high ambient temperatures can lead to bears exiting dens early, whereas cold autumns can result in earlier den entrances. Also, mild ambient temperatures and continuous food availability due to climate change could result in bears going into torpor even outside their dens (González-Bernardo et al., 2020).

2.3 Diet

Since bears are widely scattered across the globe, several diet specialties have evolved: carnivorous (polar bears, *Ursus maritimus*), herbivorous (giant pandas, *Ailuropoda melanoleuca*), insectivorous (sloth bears, *Melursus ursinus*) and omnivorous (brown bears; Carnahan et al., 2024; Galicia et al., 2021; Palei et al., 2020; Wang et al., 2017; Bojarska & Selva, 2012). Interestingly, the big differences in diets have not resulted in big differences in metabolic rates. Instead, what has shown to highly affect metabolic rate in bears is space size, where smaller spaces (small enclosures compared to big enclosures or free ranging) result in lower metabolic rates, rather than diet (Carnahan et al., 2024).

The foraging decisions of brown bears are determined by nutritional requirements and food availability (Bojarska & Selva, 2012). The diet of brown bears in central Sweden greatly varies between seasons as the food availability changes. Brown bears have been observed scavenging moose (*Alces alces*) rather than hunt them, since the moose population is decreasing in this part of Sweden (Stenset et al., 2016).

Investigating diet enables further understanding of the productivity of both brown bear populations and individuals (Persson et al., 2001. The most important factors affecting the diet of brown bears are snow conditions (depth, coverage) and ambient temperatures (Bojarska & Selva, 2012; Persson et al., 2001).

Studies have shown that brown bears are generally more carnivorous in higher altitudes, where low temperatures result in less diverse food options. This difference in diet can also be found between populations in the north versus south of Scandinavia. In the far north of Scandinavia, with long winters and very short summers, wild brown bears still shift into mainly consuming berries pre-torpor. This annual shift occurs even if ungulates (e.g. moose) are the most abundant food item in the area (Persson et al., 2001). In south-central Sweden, brown bears predominantly feed on insects (*Camponotus herculeanus* and *Formica* spp.) and moose from spring to summer, whereas berries dominate their diet in autumn. Since Scandinavian brown bears have an opportunistic diet consisting of meat, ants, berries and other vegetable options (Swenson et al., 2007; Persson et al., 2001), they select food items which maximize energy and nutrition, especially in autumn. Therefore, some berries are specifically preferred due to their fresh berry weight and carbohydrate content (Stenset et al., 2016).

Prior to winter, brown bears search intensely for food to optimize their macronutrient intake and store energy for the upcoming cold months (González-Bernardo et al., 2020; Erlenbach et al., 2014; Swenson et al., 2007). Scandinavian brown bears choose food components that are rich in poly-unsaturated fatty acids (Figure 3; Staples & Brown, 2008) such as berries (Bederska-Łojewska et al., 2021).

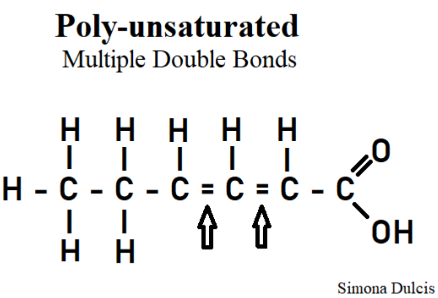

Figure 3: The structure of poly-unsaturated acid which can be found in berries; an important food item for brown bears.

Brown bears can accumulate body fat up to 35% of their total body weight (Akhremenko & Sedalishchev, 2008). About 25 days before entering a den, brown bears decrease their behavioural activity which leads to weaker activity patterns and lower appetite (Thiel et al., 2022; González-Bernardo et al., 2020; Ware et al., 2012).

When accumulating body fat for winter, the diet of Scandinavian brown bears contains up to 80% berries (Giroud et al., 2021; Stenset et al., 2016). European blueberries (*Vaccinium myrtillus*; Figure 4) and crowberries (*Empetrum nigrum*; Figure 5) are packed with antioxidants, digestible carbohydrates and lipids which are vital for brown bears especially during torpor (Giroud et al., 2019; Stenset et al., 2016).

Figure 4: European blueberries (Vaccinium myrtillus). Obtained 2023-07-03 at: https://www.plantagen.se/blabar.html

Wild individuals have shown to consume lipids in higher proportions in the autumn compared to spring and prefer lipids over carbohydrates. To maximize the density of food energy, brown bears choose lipids over digestible carbohydrates to *reduce* dietary protein. Interestingly, an absence of lipids results in the bears consuming digestible carbohydrates so that they can *optimize* their dietary protein instead (Erlenbach et al., 2014). This means that bears prefer lipids over protein and carbohydrates pre-torpor, but when lipids are scarce, brown bears will consume both carbohydrates and protein.

Figure 5: Crowberries (Empetrum nigrum). Obtained 2023-07-03 at: http://www.knipan.nu/Kraakbaer.html

2.4 Torpor Physiology

While in torpor, brown bears do not drink, eat or excrete (except for females giving birth) (González-Bernardo et al., 2020). Urea is recycled through the bloodstream and then degraded into amino acids which later reincorporates into plasma proteins (Smith & Smith, 2015). By suppressing mitochondrial metabolism (Staples & Brown, 2008), retaining poly-unsaturated fatty acids and shifting the fatty acid composition (changing the molecular structure), brown bears save energy (ATP) while in torpor (Giroud et al., 2019).

When the diet contains plant oils rich in poly-unsaturated fatty acids, such as blueberries, the bear is more likely to execute torpor with higher durations and energy savings (Bederska-Łojewska et al., 2021; Giroud et al., 2019). If food and water are inaccessible or in short supply during the summer, bears can experience kidney failure and dehydration (Hellgren, 1998).

2.5 Brown Bears in Zoos

It is common for zoological institutions to keep brown bears. This results in different living conditions for the bears, including both big and small enclosures with and without suitable environmental enrichments (Fernandez et al., 2020). In 2017, over 700 brown bears were registered at approximately 200 zoological institutions worldwide (Quintavalle Pastorino et al., 2017). Captive brown bear behaviour has been researched for decades (Podturkin, 2022; Moiseeva, 2021; Fernandez et al., 2020; Soriano et al., 2016; Watts, 2009; Montaudouin & Le Pape, 2005; Pasitschniak-Arts, 1993), leading to further knowledge specifically about stress-related behaviours at zoos, such as stereotypic behaviours (repetitive actions without goal; Montaudouin & Le Pape, 2005).

Due to the brown bear's various diet (Watts, 2009), zoos can provide various food items depending on season and availability. Unfortunately, this also means that some important nutritional components can get overlooked. A recent study by Robbins et al. (2022) found that most zoos keeping brown bears must update the zoo diet to ensure welfare and minimize medical conditions. The percentage of protein in brown bear diets at most zoos is higher than the diet of wild individuals (Robbins et al., 2022; Erlenbach et al., 2014). To ensure better health and welfare of captive brown bears, their diet should consist of about 20% protein, 30% fat and the rest of digestible carbohydrates and nutrients from berries, fruit and vegetables (Erlenbach et al., 2014).

2.6 Purpose of the Study

Since little is known about the pre-torpor behaviours of brown bears in captivity, this project investigated the effects of ambient temperatures on captive brown bears' behavioural activity prior to winter. The different components of the zoo-diet were also investigated through literature research.

The hypotheses were that (1) the two bears would show a higher behavioural activity during high temperatures compared to low temperatures, and (2) their behavioural activity would decrease in the month prior to torpor.

3 Method & materials

3.1 Animals

The animals observed in this study were two brown bear brothers called Bamse (Figure 6a) and Bart (Figure 6b) at Kolmården Zoo in Sweden. The two brothers were born 2002 in the Swedish wilderness of Hälsingland county. After their mother died due to a vehicle accident, they were taken to Orsa Predator Park as cubs. The bears were transferred to Kolmården Zoo in 2005 and have been kept together since. Bamse was castrated in 2008 but Bart has been able to reproduce successfully. The bears had previously not shown any aggressive behaviours towards humans. Kolmården Zoo has six other brown bears in the park though they had to be excluded from the study due to structural limitations meaning that behavioural observations were not possible.

Figure 6: Bamse (A) and Bart (B) the brown bear brothers at Kolmården Zoo, Sweden.
© Dearbhaile Nollaig Nì Dhubhghaill (A), Simona Dulcis (B)

The bears were well-habituated to human presence. They interacted with humans in the park about four times a day on average, but this varied between seasons. It was considered an interaction when the bears noticed a human while feeding, getting treats, enrichment etc.

Prior to the study, the two bears were healthy and stable without any diseases. The only thing noted was that the quality of their fur was in worse condition than the other bears at the zoo housed in larger enclosures, especially in spring.

The bears at Kolmården Zoo usually start their torpor in late November and wake up in the beginning of April. All bears are given the same diet where the components were distributed as evenly as possible between individuals.

The bear diet at the zoo varies throughout the year (Table 1), but usually they are given 0.5-1 kg of dog pellets per day. In the spring, the diet consists mostly of meat and fish. The amount of offered vegetables increases until October. In late August, some of the vegetables are replaced by fruit. At this time, the amount of offered meat and fish is decreased. In mid-October, the diet consists of only fruit and a small amount of animal protein. The offered amount of food is decreased until about a week before torpor. One week before torpor (around mid-November), the bears stop eating and no food is offered at that time.

Table 1: The overall food-ratio schedule for the brown bears each season at Kolmården Zoo. For food component details, see *3.2.4 Diet*. Arrow explanations: ↑: Food component offered in higher amount compared to other components, ↓: food component is decreasing fast and is offered in lower amount compared to other components, ↗: food component is slowly increasing in offered amount but still lower compared to other components, ↘ food component is slowly decreasing in offered amount, - : no amount of this food component is offered.

Season	Animal protein	Vegetables	Fruit	Dog pellets (kg)
Summer	↑	↑	↗	↑
Autumn	↓	↘	↑	↑
Winter	-	-	↑	-
Spring	↑	↗	-	↑

Information was provided about which food type (vegetables, fish, fruit etc.) the bears recieved each day. Unfortunately, the independent weights of the apples, oranges, carrots etc. were not possible to obtain. To investigate the bears' diets, the food components were researched further through literature to gather information about possible health effects.

3.2 Procedure

3.2.1 Time Plan

Behavioural data were collected three days per week between September 25th and December 4th 2023 to time the pre-torpor behaviours of the bears. The observations mostly took place outside the bear enclosure (Figure 7) during low season (to minimize visitor interference). It was possible to walk around the entire enclosure.

The bears were locked in their internal enclosure to sleep on November 27th, so the behavioural data between November 27th – December 4th was excluded due to the inability of the bears

Figure 7: The enclosure (within the white marking) of Bart and Bamse the brown bears at Kolmården Zoo with its' total space of 2 765 m^2.

to go outside, leaving a total of 28 observation days. Also, the internal room temperature was stable at 15 °C and the bears were mostly inactive after being locked inside.

3.2.2 Behavioural observation

Figure 8: Bamse the brown bear being inactive inside the bear house at Kolmården Zoo. 1: Entrance-room, 2 & 3: dens

Each observation session lasted six hours, three hours in the morning and three in the afternoon. Ethograms (see *Appendix*) were used to observe different active and inactive behaviours of the bears (Table 2). Continuous sampling on one focal animal was done in one-minute intervals, with the focal animal switching every 30 minutes. Each observed behaviour was timed in seconds and noted. Live video surveillance was also used for observations when the bears were inside the bear house. On one side of the bear house, video surveillance covered a room with two dens (Figure 8), that also had video surveillance, whereas the other side had its' video surveillance removed before the current study took place. All behaviours from the ethograms and other behaviours such as stereotypies etc., were noted (Table 2).

Table 2: Bear behaviours considered as active/inactive.

Active behaviours	**Inactive behaviours**
Walking	Sitting
Running	Lying down
Standing still	
Playing	
Standing on hind legs	
Tree back-scratching	
Nesting/Digging	
Negative interaction*	
Stereotypic*	
Scratching (other)	

**Negative interaction: aggressive/provocative behaviour towards conspecific or keeper.*
**Stereotypic: stress-related behaviours such as pacing, head-rolling, gnawing intensely on non-food object, other self-destructive behaviours, refusing to eat, etc.*

3.2.3 Ambient Temperature Collection

Ambient temperature data for the observation period was downloaded in spring 2024 from the open dataset of the Swedish Meteorological and Hydrological Institute (SMHI; https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer/#param=airtemperatureInstant,stations=core). The temperature data was obtained from the station of *Kolmården-Strömsfors A*.

3.2.4 Diet

The two bears were offered a varied diet with fruit (Figure 9), vegetables, animal protein (Table 3) and minerals. As the time for torpor approached, the amount of animal protein decreased until only fruit was offered. About one week before the bears got locked inside, no food was offered.

The bears received almost no dog pellets during the days of observation. Dog pellets were occasionally (about three times) part of the bears' enrichments.

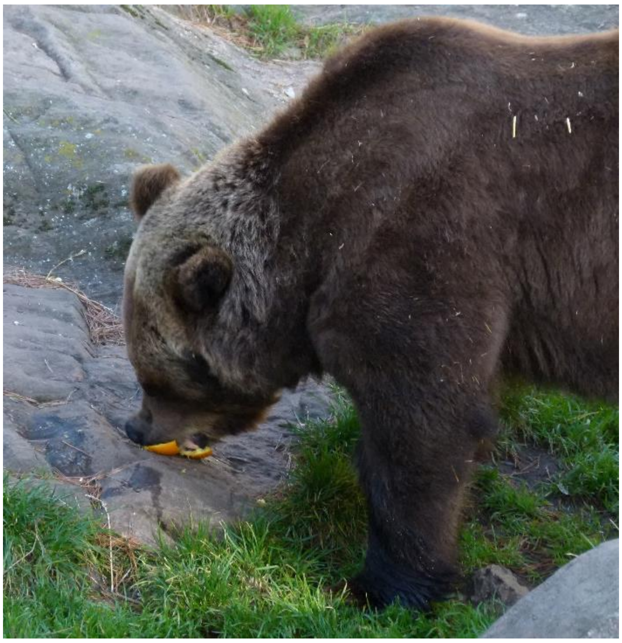

Figure 9: Bart the brown bear gnawing on a slice of orange at Kolmården Zoo, Sweden.
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Table 3: Details on food components given in September-November 2023.

Vegetables & fruit	Animal protein
Carrots, Fennel, Parsnip, Cucumber, Green leaf lettuce, Tomatoes, Net- and honey melon, Apples, Plum, Orange	Dog pellets (Pure Natural, Smaak), Horse (*Equidae*), Beef (*Bos taurus*), Intestines, Herring (*Clupea harengus*), Capelin (*Mallotus villosus*)

3.2.5 Data analysis

For the behavioural activity analysis, a comparison was made between individuals, months, and active vs inactive behaviours. The total duration of active behaviours was divided by total observation time x 100 (%).

For the ambient temperature analysis, a correlation (95% confidence interval, without assuming equal variances) was tested between average ambient temperature per day and the bears' average behavioural activity per day.

4 Results

4.1 General Behavioural Observation

Both individuals spent more than 50% of the observation time being *out of sight* (OS) and the behaviour which was shown the most by both bears was *lying down* (inactive; Figure 10).

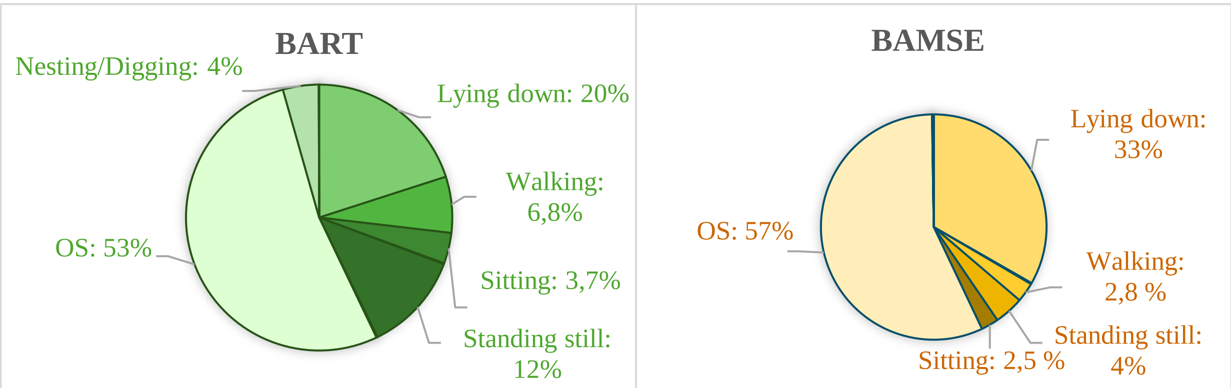

Figure 10: Bart and Bamse the brown bears' total general behavioural distributions in % at Kolmården Zoo, Sweden.

4.2 Active Behaviours

Both Bart and Bamse performed *walking* and *standing still* significantly more than other active behaviours (ANOVA (type II tests): Df = 10, p << 0.001; Df = 9, p << 0.001 respectively; Figure 11).

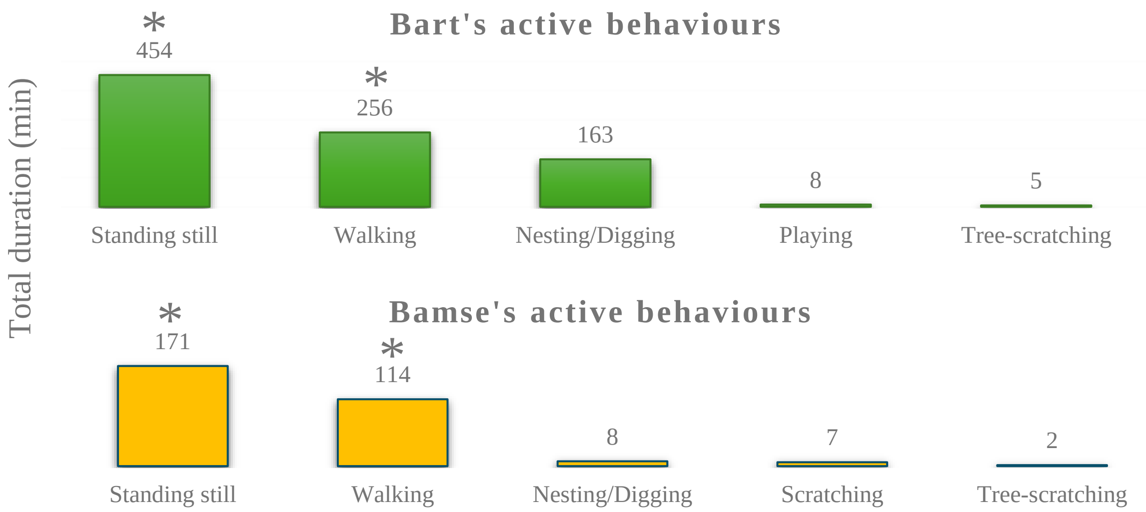

*Figure 11: Bart and Bamse the brown bears' total durations (min) of active behaviours at Kolmården Zoo, Sweden. The * shows statistically significant differences.*

4.3 Ambient temperature and behavioural activity

Bart showed a trend of being more behaviourally active compared to Bamse (Figure 12), but the activity duration did not differ significantly between individuals (one-way ANOVA not assuming equal variances: p = 0.16).

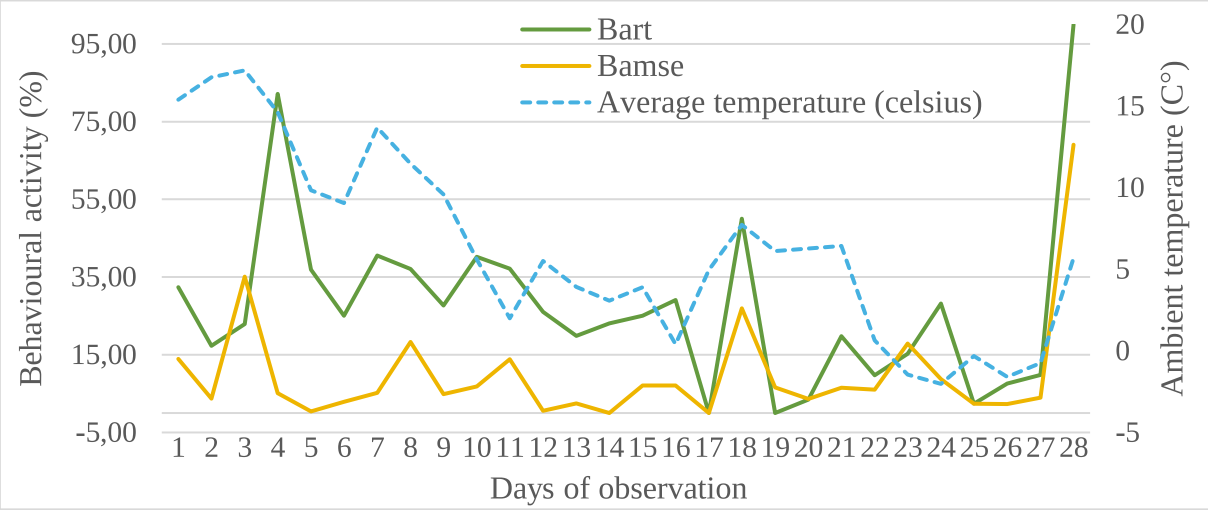

Figure 12: Bart and Bamse the brown bears' behavioural activity per day (%) shown along with the average ambient temperature (°C).

Bart's duration of behavioural activity did not correlate significantly with the ambient temperature (R^2 = 0.004, p = 0.29; Figure 13).

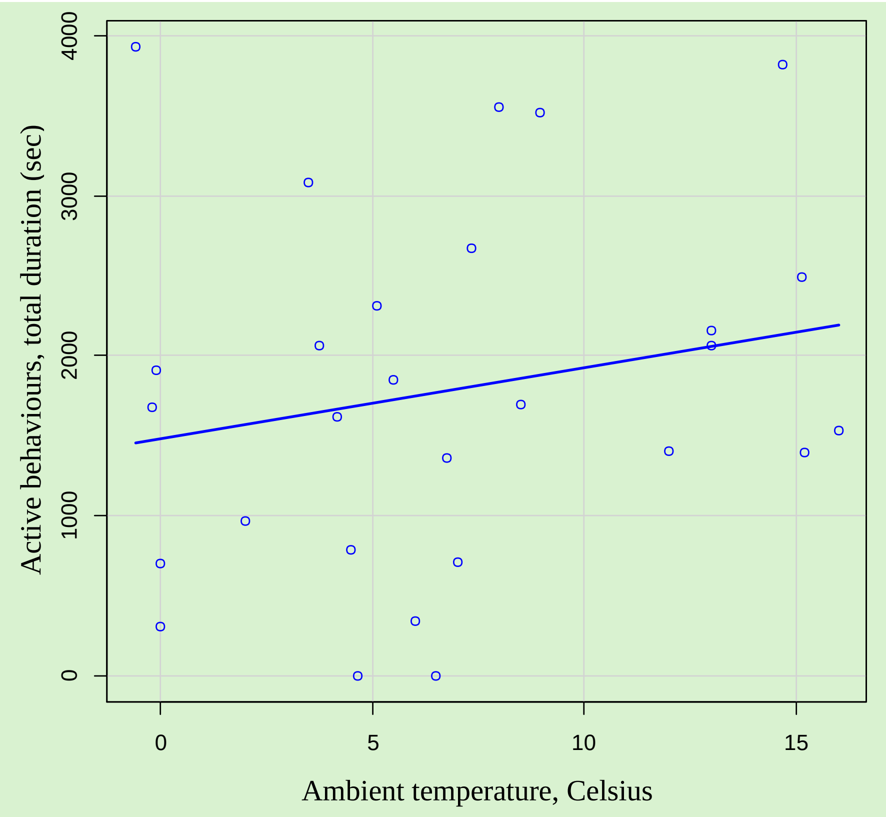

Figure 13: Bart the brown bear's total duration (sec) of active behaviours per day along with the average ambient temperature (°C) each day.

Bamse's duration in behavioural activity did not correlate significantly with the ambient temperature either (R2 = 0,001, p = 0,84; Figure 14).

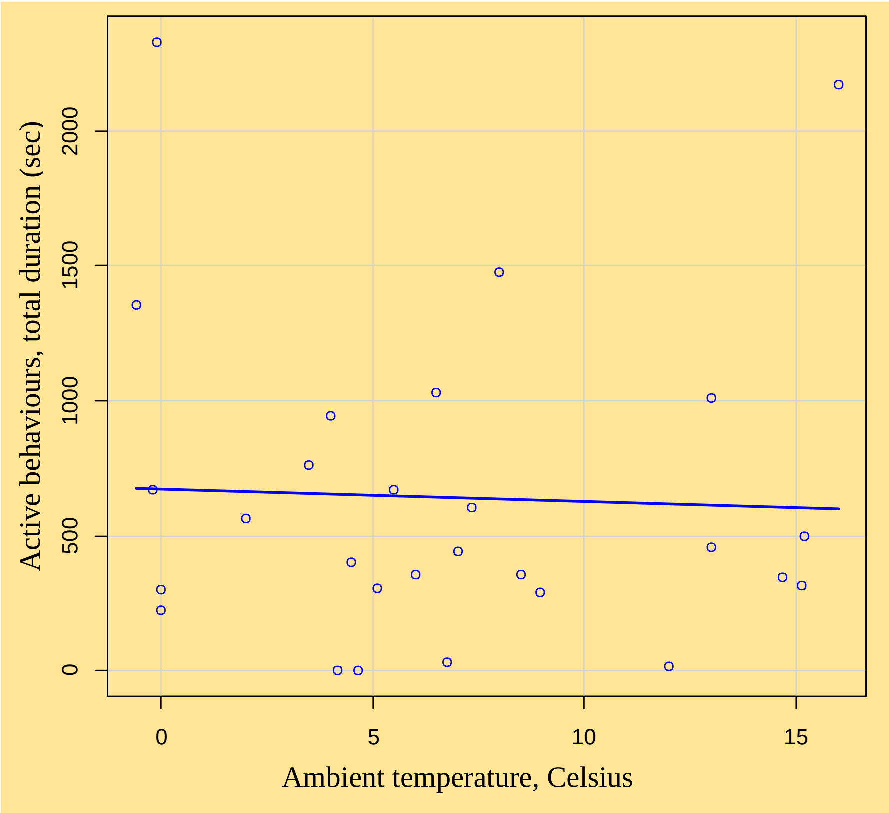

Figure 14: Bamse the brown bear's total duration (sec) of active behaviours per day along with the average ambient temperature (°C) each day.

4.4 Behavioural activity between months

Bart's duration of active behaviours differed significantly between September and November (ANOVA p < 0.001) and October and November (p < 0.001). Bamse's activity duration also differed significantly between October and November (p = 0.008; Figure 15).

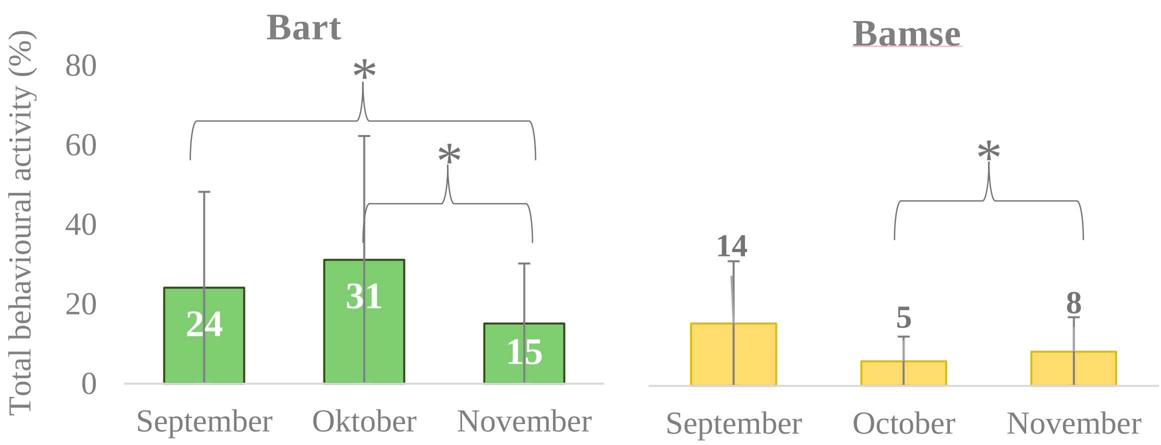

*Figure 15: The total behavioural activity (%) of the two brown bears Bart and Bamse in September-November 2023 at Kolmården Zoo, Sweden. * Show statistically significant differences.*

5 Discussion

5.1 Behavioural activity

The lack of support for the first hypothesis (the two bears would show a higher behavioural activity during high temperatures compared to low temperatures) could have been due to the very high durations of *Out of sight*. Since Bart showed a tendency of being behaviourally active depending on ambient temperature, it might have been statistically significant with higher amounts of observational data. The bears were out of sight due to two factors, one was due to the structure of the enclosure (big rocks and cracks in the mountain hiding the bears), the other was due to the lack of video surveillance inside part of the bear house. Since only half of the bear house had supervision, no observations were possible when the bears were in the unsupervised section. The bears were very affected by my presence inside the house, since they were expecting food, which affected my ability to conduct behavioural observations. Also, the supervised part of the building was locked about two weeks before torpor, which led to the two bears only having access to the unsupervised part when it was time for torpor.

Both captive and wild brown bears have shown to spend about 50% of their time being inactive and the rest of the time foraging, eating and doing locomotion (Quintavalle Pastorino et al., 2017; MacHutchon, 2001). This aligns with the results of the current study.

One of the possible reasons to why Bamse showed an overall lower activity level compared to Bart is that Bamse is castrated. Behavioural activity has been shown to decrease after castration in both domestic cats (Ferreira et al., 2020) and dogs (Kriese et al., 2022), so this could be the case for bears as well.

During torpor, the testosterone levels have shown to increase in sexually active (intact) males. One possible reason for this is to keep androgen action stable (Frøbert et al., 2022) to ensure muscle mass does not decrease (Bhasin et al., 2003) even if the bear is behaviourally inactive. This could suggest that castrated males like Bamse lose muscle mass while in torpor, which in time might make them more tired from spending energy rebuilding muscle tissue compared to an intact male like Bart.

Since behavioural activity *patterns* weaken when the general activity *level* decrease, (Thiel et al., 2022; González-Bernardo et al., 2020; Ware et al., 2012), these patterns could become less important to execute for the individual. Bamse was unusually inactive in September and October. Both bears were also scratching themselves a lot in the beginning of the observation period; they later stopped scratching after getting worm treatment. This could also have affected their behavioural activity, since dealing with possible parasites might drain the overall physical energy of the bears.

Another possible reason for the insignificant results in behavioural activity versus ambient temperature is that both bears were often sitting or standing still waiting for food instead of actively foraging, no matter the ambient temperature, meaning there may be no reason for them to walk around the enclosure before food is dispersed. Also, wild brown bears tend to ambush prey, where they stalk, sit and wait, or calmly forage berries in autumn (Pagano et al., 2018), which aligns with the feeding behaviours of the two bears at Kolmården Zoo.

5.2 Diet

No berries were provided to the bears during the observation period. Bart and Bamse seemed to prefer fruit over vegtetables, and occasionally over fish. Close to torpor, the bears recieved mostly apples and oranges.

5.2.1 Is the Lack of Berries a Problem?

Blueberries contain more nutrients than just fatty acids, they are also rich in antioxidants, vitamin C and E, Manganese, K1, vitamin B6, copper, fibre, minerals and bioactive units, which decrease risks of heart and blood-related diseases (Pires et al., 2020; Chu et al., 2011). Apples and oranges, which were given at the highest ratio to the bears close to torpor, contain vitamins B and C, antioxidants, fibre, carbohydrates, folic acid, carotenes and flavonoids (Saini et al., 2022; Etebu & Nwauzoma, 2014; Boyer & Liu, 2004; Manville et al., 1936).

Some fruit seeds, such as apple seeds, contain the vital poly-unsaturated fatty acids (Akšić et al., 2021). However, depending on where the apples are produced, their nutritional value can differ (Akšić et al., 2021; Neilsen et al., 2008). Therefore, it might be worth looking into which kind of apples the bears get fed in the autumn and early winter, when the apple ratio in their diet is the highest.

As previously mentioned, blueberries contain lipids which favours a successful, healthy torpor in brown bears. Without these lipids, the bears must obtain digestible carbohydrates instead. Since wild bears have been observed consuming digestible carbohydrates pre-torpor as an alternative to berries, there might be a reason for that choice. It is possible that only consuming apples, without enough poly-unsaturated rich seed oil, before torpor results in negative long-term effects for the brown bears, but this is just a speculation.

Studies have shown that omega-3-poly-unsaturated fatty acids (precursors in the metabolic pathway to ATP, energy) are retained in the white adipose tissues of brown bears while denning, whereas short fatty acids are released into the blood plasma (Giroud et al., 2019). Since no berries were provided to the bears in this study, the main source of omega-3 was fish. Vegetable omea-3 sources are, for instance, red leaf lettuce, spinach and olive oil (List & Plan, 2023). Interestingly, when omega-3-acids are given as diet enrichments, the probability of executing torpor decrease (Giroud et al., 2019).

5.2.2 Are Apples and Oranges Enough to Replace Blueberries?

Even if apples contain important nutrients such as ascorbic acid (vitamin C) and polyunsaturated fatty acids (Bajramova & Spégel, 2022), the concentration of fatty acids is much lower compared to berries (Bajramova & Spégel, 2022; Dai et al., 2021; Buena et al., 2012). In comparison, the cell membrane in oranges is considered partly built of fatty acids, resulting in a higher concentration of fatty acids compared to apples (Habibi et al., 2021) but still a lower concentration compared to blueberries (Dai et al., 2021; Buena et al., 2012).

Depending on how oranges are stored and transported, the fatty acid composition, including polyunsaturated fatty acids, differs (Habibi et al., 2021); this also applies for blueberries (Buena et al., 2012). Since the climate of Sweden is not suitable for growing oranges, transportation is needed to access them. This might lead to a higher number of oranges with lower nutritional quality compared to native alternatives. Blueberries are also transported, but they might have a higher nutritional quality since they also grow naturally in Swedish boreal forests.

Blueberries have a similar sugar content to apples and oranges (Pérez-Cid et al., 2022; Zhang et al., 2020; Jamil et al., 2015).

5.2.3 Animal Protein

During the observation period of this study, the two bears mostly got animal protein from fish. Baltic Sea fish, including herring, can contribute to several health risks due to the poor quality of the Baltic Sea ecosystem (Bleckner et al., 2021; Tuomisto et al., 2020; Pihlajamäki et al., 2019; Skerfying et al., 1999). Capelin, on the other hand, has been shown to provide mainly positive health effects (Yin et al., 2023) and is rich in poly-unsaturated fatty acids (Pedro et al., 2020; Henderson et al., 1984).

The two bears got very little dog pellets during this study; therefore, its effect could not be discussed. Additional minerals were provided whenever red meat was offered to make up for the loss of intestinal nutrition in whole carcasses.

Occasionally (on average once or twice per week), the bears preferred fruit and vegetables over fish, eating them first or solely. This aligns with the pre-torpor behaviours of brown bears in Alaska. They have been observed spending many hours per day foraging berries, even if the access to salmon is close to unlimited. Brown bears seem to avoid animal protein prior to torpor (Robbins et al., 2022). One possible explanation to this protein avoidance could come from a study on captive mice, where their body temperature decreased during periods of protein restriction (Mitchell et al., 2015), which suggests there could be a similar effect on the body temperatures of brown bears.

5.2.4 Optimal diet

Wild brown bears seem to prefer lipids over carbohydrates, and carbohydrates over protein (Erlenbach et al., 2014; Felicetti et al., 2003). Therefore, dry pellets containing less protein and more fat might be a more suitable option than providing regular dog pellets which usually have a higher protein percentage (Robbins et al., 2022). About 68% of the metabolized energy in brown bears comes from fat (Erlenbach et al., 2014), therefore, adding more poly-unsaturated lipids in the diet is recommended to increase the health state of the brown bears (De Cuyper et al., 2023). These lipids can be offered as previously mentioned through plant oil (such as blue- or boysenberry, perilla, chia or flax seed oil; Abedi & Sahari, 2014) and dry pellets (Robbins et al., 2022).

Both Bart and Bamse seemed to have a higher body mass than the average for brown bears. According to zoo staff, the two bears do not change much in body shape after torpor. This could be explained by the fact that brown bears have a slow carbohydrate metabolism during torpor (Ahlquist et al., 1984). This also suggests that if Bart and Bamse get a higher average amount of carbohydrates than required, obesity is “one chew away”. This could raise concerns about the physical health of the two bears. Obese humans and house cats can eventually develop diabetes and cardiovascular diseases (Osto & Lutz, 2015). Brown bear physiology gives an advantage regarding diabetes. While in torpor, adipocytes of bears are insulin resistant, but when the bear is active, the adipocytes become insulin sensitive (Rigano et al., 2017). Due to brown bears’ physiological capabilities, a diet including lipids appear to be the main factor to why bears do not develop diabetes (Tekin et al., 2023).

5.3 Fur quality

The female bears at Kolmården Zoo were born in captivity, since Bart was born in the wild, he was not allowed to mate with them to prevent breeding hybrid bears. Since Bart and Bamse do not take part in a breeding program, they were moved to a different enclosure to separate them from the fertile females. After changing to a smaller enclosure in 2021, fur quality decreased in both Bamse and Bart, with the fur becoming becoming less shiny with an uneven texture. This was also the case for another brown bear male called Varulven, who inhabited the smaller enclosure before Bart and Bamse.

One reason for oily fur quality is skin secretion. The secreting capacity of the sebaceous glands of the back skin of males seem to be testosterone regulated. Castrated males have shown to lack glands and therefore, the oily secretion (Tomiyasu et al., 2018). An investigation of the water quality in the enclosure's pond might rule out chemicals in the water affecting the skin of the two bears. Fur quality can be an indicator of overall health of an individual (Liu et al., 2019). Since a veterinarian has not examined Bart and Bamse since they changed enclosure, a general health assessment could be important to rule out physiological factors affecting the low fur quality of Bart and Bamse. Castration has also shown to alter the fur quality (Kristoffersson, 2022), which could be one of the reasons to why Bamse had slightly worse fur quality compared to Bart.

5.4 Improving welfare

Brown bears are known to have large home ranges and therefore, tend to move long distances (Pagano et al., 2018). The home ranges of wild brown bear males change throughout the year (between 400-1500 km^2) due to environmental disturbance (e.g. hunting), food and female availability (Gosselin et al., 2017; Dahle & Swenson, 2003). At Kolmården Zoo, the enclosure was only a fraction of a wild home range, approximately 2700 m^2. Since the enclosure space differs greatly from the bears' wild preferences, it could affect Bart and Bamse negatively over time.

One factor which often influences the development of obesity at zoos is enclosure size, since a small enclosure often limits physical activity. On the other hand, studies have found that increasing physical activity might not be an effective approach in weight management. Restrictions in calorie intake, however, have shown to be more effective and adjustable (Kleinlugtenbelt et al., 2023).

Personality profiles are an important tool when improving welfare on an individual level. Bears have shown behavioural differences that traces back to individuality, which in turn supports the idea of different personality types within species (Quintavalle Pastorino et al., 2017; Fagen & Fagen, 1996). Providing enrichment or tasks that suit the different personalities of Bart and Bamse might result in good mental health and, therefore, improved welfare.

5.4.1 Comments & Enrichment

Enrichment is an effective way to increase animal welfare in captivity, leading to less stressed individuals and more natural, exploratory behaviours (Wagman et al., 2018; Soriano et al., 2016; Law & Reid, 2010; Carlstead et al., 1991). Enrichments should not compensate for enclosures with a poor design, instead, a well-adapted enclosure with planned suitable environmental enrichments should increase the welfare of captive bears (Law & Reid, 2010). Ideas of improvement such as more time and resources for environmental enrichments and training sessions, more complex feeding devices and a bigger enclosure more suited for bears have been mentioned.

Behaviour-based enrichments invite species-specific strategies of feeding, nesting, exploring, etc. Even if captive environments differ from wild circumstances in many ways, similar opportunities can still be offered to the bears; for instance, the ability to torpor or nest outside (Babitz et al., 2023) or a simulation of an underground den. Bamse and Bart occasionally move around inside the house during torpor, but unfortunately, they cannot torpor outside due to safety reasons (trees inside and around the enclosure falling while unsupervised). Other bears at the zoo in bigger enclosures have trees which are attached with wires that block fallouts. Because of this, those bears can choose to torpor outside.

Food is a very important and time-consuming part of the life strategies of wild brown bears (Babitz et al., 2023). Therefore, enrichments specialized in various food displays are important. Some enrichment ideas provided by Babitz et al. (2023) are rotting logs with insects, several trees or high platforms with hidden fruit, berry-picking, buried larvae and seasonal fishing. One possibly amusing enrichment tip, which could be interesting for zoo-visitors, is to put honey inside logs. It appears that using novel logs are more enriching than re-used ones (Carlstead et al., 1991). Also, variable durations and schedules of enrichments have shown to decrease stress-related behaviours more effectively compared to fixed-time and scheduled enrichments (Wagman et al., 2018).

The behavioural pattern for foraging bears is divided into seeking, preparing and then consuming food. This should be taken into consideration when planning enrichments (Babitz et al., 2023). Since brown bears often rely on their vision while foraging (Ordiz et al., 2012; Swenson et al., 2000), providing colourful enrichments might increase the bears foraging interest. Other enrichment ideas include smoothies and scattering smaller pieces of food. This way, the bears cannot eat as quickly and will spend more time foraging like individuals do in the wild.

Studies have found that bears can become food-conditioned, not only by learning from the mother, but also through social learning (Hopkins III, 2013; Mazur & Seher, 2008). Hand-reared brown bear cubs have been shown to reach a higher body mass quicker compared to wild cubs of the same age (Huber et al., 1993). Since Bart and Bamse were taken into captivity as cubs, their feeding habits might have altered into becoming more food-conditioned and, therefore, possibly becoming lazy foragers.

Relative to body size, bears have the largest brains of all carnivores. Though their ability to solve tasks is probably underestimated by most, delicate tool use has been observed in a wild brown bear in Alaska picking rocks to scratch itself (Deecke, 2012). Therefore, enrichments involving object manipulation tasks could result in further learning and use of motor skills, and in turn increase the self-confidence and mental health of the bears.

5.5 Limitations of the study

Various limitations applied to the current study. The first one was limited observational time due to the opening hours of the zoo. Another limitation was the lack of video surveillance, especially close to torpor since half of the bear house was not accessible. The limited details of food component amounts made it difficult to collect measurable data for statistical testing. Other data collection ideas were denied, such as blood sampling and weighing body mass. Since the current study is a master's thesis, the window of data collection was somewhat fixed, making it difficult to do corrections. Of course, the window of observational time was also limited due to the timing of the brown bears torpor; thus, this is the lesser limitation. When the current study started, the intention was to compare the two bears' behavioural data with brown bears at another zoo. Unfortunately, the other zoo did not participate in the end.

5.6 For future studies

A bigger dataset is needed to further investigate captured brown bears' behavioural activity compared to the ambient temperature. To get constant, accurate data effectively, other equipment is also needed, such as bracelets, collars or tags with GPS and acceleratory measurements (Scott et al., 2016; Brown et al., 2013). If devices like these are used, the obtaining of data is not hindered by a zoo's opening hours or material construction (small, inaccessible spaces etc.) and is equally obtained 24/7 for both behavioural activity and ambient temperature.

5.7 Conclusion

Though the two brown bear brothers were born in the wild, their behavioural activity did not correlate with the ambient temperature. Their diet might need updating with lipid-rich, plant-based food, especially before torpor, with less protein and more species-specific food enrichments. The two bears showed similar behaviours to individuals in the wild, spending most of their time foraging or being inactive. The enclosure was inadequate regarding size and supervision. Since the fur quality was in worse shape in both bears, health checks might be needed to ensure physical welfare. Overall, the results show a need for a bigger dataset and sample size to provide an accurate picture of reality for the behavioural activity of captive compared to wild brown bears with regards to different ambient temperatures.

6 Societal and ethical considerations

The current study was necessary since both Bart and Bamse showed signs of possible distress; worse fur quality and lower behavioural activity than usual. The study was executed to further understand how to improve welfare of the two brown bears at Kolmården Zoo. Improving the conditions of the bears would serve as a model of good welfare to the society and other zoos.

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Appendix 1: The ethogram of captive brown bears, obtained at Podturkin (2022).

Behaviour Category	Behaviour	Description
Inactivity	Inactive	*Individual is lying down with eyes open or closed, or sitting or standing, performing no other behaviours.*
Activity	Locomotion	*Individual is walking from one place to another on land or in water, performing no other food-related or abnormal behaviours.*
	Foraging	*Individual is consuming food (visible jaw movement), sniffing or manipulating the environment or object.*
	Behaviour directed at non-food enrichment	*Individual is sniffing or/and manipulating an enrichment object.*
	Self-directed behaviour	*Individual is scratching or licking itself, rubbing against an object, and/or auto-grooming.*
Abnormal behaviour	Pacing	*Individual is performing a repetitive movement (with no apparent goal or function) during which the animal repeats the exact movement for greater than three cycles.*
Out of sight		*Individual is out of sight due to the bear being hidden or inside an object, building or interior.*

Appendix 2: The ethogram of the current study

Behaviour	**Description**
Walking	The individual is moving from one place to another (without doing any other behaviour)
Sitting	The individual is putting its body weight mainly on the behind (without doing any other behaviour)
Lying down	The individual is touching the floor/ground/surface with belly and chest while relaxing all four legs (without doing any other behaviour)
Scratching	The individual is manipulating fur/skin with claws
Vocalizing	The individual is producing sound
Running	The individual is moving from one place to another in a faster pace than walking, moving all four legs quicker
Standing still	The individual stays in place while standing on all four rams without doing any other behaviour
Playing	The individual is behaving energetically, manipulating object/water alone without consuming food/drinking
Swimming	Moving its body through water from one place to another
Standing on hind legs	The individual puts its body weight on the hind legs
Tree back-scratching	The individual puts its body weight on the hind legs while rubbing its back up and down against a tree
Nesting/Digging	The individual is using its rams to move around dirt/soil/nesting material
Negative interaction	The individual is making an energetic display (moving towards conspecific, vocalizing with tense body posture) resulting in withdrawal of another conspecific
Stereotypic	Scratching/bounching against a firm object (e.g. wall, door) repeatedly